FEDERAL UNIVERSITY OF SÃO PAULO

INSTITUTE OF SCIENCE AND TECHNOLOGY

PROFESSIONAL MASTER DEGREE OF TECHNOLOGICAL INNOVATION

SUPPLIER QUALITY MANAGEMENT: AN APPLICATION OF LOGISTIC REGRESSION IN THE RISK ANALYSIS

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2019

This work is specially dedicated to my wife ***Talita****, my daughter* ***Pietra****, my father* ***Pedro*** *and my mother* ***Angélica*** *and to my whole family, Bárbara, Úrsula, Catarina, Tiago, Ricardo, Tatiane, Valentina, Isadora Renato, Josiane, Ryan, Alice, Vagner, Marilda, Bruno, Pamela, Livia, Lara and Luisa.*

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I am thankful to my wife Talita for her patience and dedication with me and our daughter Pietra. This work is part of the plan that we have been built for our lives and this seed will bring us good winds in a blue sky.

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Finally, I want to thank God who illuminated my thinking and gave me courage, force, health and knowledge to start and conclude this work.

"Without a standard there is no logical basis for making a decision or taking action."

Joseph M. Juran

Resumo

O gerenciamento da qualidade dos fornecedores é um dos principais desafios na gestão da cadeia de fornecimento. Alguns aspectos associados a este fato são: a quantidade de demandas contra um limitado número de fornecedores; a busca por novos produtos de alta tecnologia; o constante desenvolvimento de produtos devido a obsolescência de seus componentes e por fim, a demanda dos clientes por produtos de baixo custo, com qualidade e entrega no prazo. Uma das abordagens mais investigada na gestão de fornecedores é a análise de risco, a qual tem como objetivo identificar potenciais problemas antecipadamente e proporcionar tempo hábil para correções ou melhorias. Entretanto, existem questionamentos sobre quais métodos são melhores e como são aplicados. Neste contexto, este trabalho realizou uma revisão da literatura e considerando os métodos encontrados, foi aplicado um modelo de regressão logística como uma proposta alternativa para a análise de risco realizada sobre a qualidade dos fornecedores de uma empresa do setor aeronáutico. O modelo foi analisado com base nos resultados da aplicação da regressão logística e no risco calculado pela empresa de alguns fornecedores.

Palavras-chave*: Cadeia de Fornecedores, Gerenciamento de Risco, Gerenciamento da Qualidade dos Fornecedores, Regressão Logística.*

Abstract

Supplier quality management is one of the key supply chain challenges. Some contributors are: the number of demands against a limited number of suppliers, the search for new high technology products, the constant development of products due to the component obsolescence and finally the demand of customers for low-cost products with good quality and on time delivery. One of the most investigated supplier's management approach is risk analysis, which aims to identify potential problems in advance and provide time for corrections or improvements. However, there are questions about which methods are best and how they are applied. In this context, the present work executed a systematic literature review and considering the most methods used, was applied a logistic regression model as an alternative proposal for the risk analysis performed in the supplier's quality management of an aerospace company. The model was analyzed based on the logistic regression model and the risk calculated by the company.

Keywords: *Supply Chain, Risk Management, Supplier Quality Management, Logistic Regression.*

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List of Acronyms

ANAC – National Civil Aviation Agency

FAA – Federal Aviation Administration

OEM – Original Equipment Manufacturer

SCM – Supply Chain Management

SQM – Supplier Quality Management

SLR – Systematic Literature Review

TQM – Total Quality Management

CoPQ – Cost of Poor Quality

FMEA – Failure Mode and Effect Analysis

CNQ – Cost of non-Quality

PPM – Parts per million

PPAP – Production Parts Approval Process

AHP – Analytic Hierarchy Process

ANP – Analytic Network Process

RQ – *Research Question*

AS9100 – Aerospace Standard

CNQ – Cost of Non-Quality

OR – *Odds ratio*

Summary

Chapter 1

INTRODUCTION

This chapter present the current scenario in the aerospace sector, a problem contextualization, the research questions, the objectives and an explanation on how this work is structured.

1.1 Contextualization

Innovation and technology are becoming partners in product development and people's life transformation. Customers are demanding interesting and reliable products consistently delivered faster, on time, with no damage, and with good quality (Mentzer et al., 2001).

A rapidly changing technology, the complexity of products and the growth of competition are challenging the original equipment manufacturers (OEM) to seek suppliers who will provide low-cost products with good quality and high performance. In the aerospace company, this seeks are raising and becoming fundamental due to the limited technical capability of suppliers, product complexity, technology uncertainty and high quantity of requirements defined by the aerospace authorities (e.g. National Civil Aviation Agency in Brazil – ANAC and Federal Aviation Administration - FAA in the United States of America).

The aerospace OEM has a constant development of multiple components being done by different suppliers at the same time and all of them shall be coordinated to guarantee that project expectation will be achieved. However, Hong et al. (2009) assert that it is common to find situations where poor coordination with suppliers during product development projects resulted in delays in the product introduction and increased development costs.

A real case is from Boeing, a company from the United States of America that experienced a delay in the delivery of its new wide-body jet (the 787 Dreamliner), attributing this to the supply chain challenges of the program and difficulties among suppliers in bringing together all of the components (Lunsford, 2008).

For Denning (2013), the outsourcing strategy adopted by Boeing, which was more than 70% of aircraft parts were outsourced (for the 737 and 747 it had been at around 35-50 percent) contributed to the unsuccessful of 787 Dreamliner project. Boing sent hundreds of its engineers to the sites of various Tier-1, Tier-2, or Tier-3 suppliers worldwide to solve various technical problems that appeared.

Consequently, in 2013 some of the airlines (as Japan Airlines and United Airlines) had emergency events during the flight due to a fire caused by the battery overheating of the Auxiliary Power Unit in the rear fuselage. FAA immediately issued an emergency airworthiness directive ordering all USA based airlines to ground their Boeing 787s until yet-to-be-determined modifications were made to the electrical system to reduce the risk of the battery overheating or catching fire. This was the first time that the FAA has grounded an airliner type since 1979 (Song et al.*,* 2014).

To manage a worldwide supply chain with a variety of products (such as Electrical, Electronic, Mechanical, Chemical, and Composites products) and technologies and also to avoid such situation with 787 Dreamliner project, an aerospace company, which will be considered a case study in this work, have a dedicated team to deal with all the supply chain and is responsible to work with others areas in the company, starting with supplier selection phase, during the product development, up to series production to guarantee on-time delivery of reliable aircraft to the customer.

This team is named Suppliers Quality Management (SQM), which should be concerned with the sourcing, evaluation and selection of suppliers, provision of education and training, monitoring of supplier performance and supplier certification as stated by Yeung and Chin (2004).

About quality, Matthews (2006) asserts that the SQM must transform itself from simply measurement supplier compliance to gathering knowledge, managing risk and executing project management through Total Quality Management, which ensures that the process is followed and customers are satisfied.

It is important to have a correct strategy identification for risk mitigation considering the uncertainty that affects the industry about the supply chain (Costantino, Pellegrino, 2010).

1.2 Problem Definition

Most of the companies have a challenge to deal with its worldwide and restricted supplier chain, due to the variety of technologies, suppliers' locations, low-quality product performance and the OEM competitors – same supply chain shall attend customer demanding for parts at the same time. In this case, some solutions could be proposed:

1) To increase the SQM team – which would demand investment to hire capable people.
2) To spread the supply chain, seeking small or medium suppliers – this would demand more people to deal with the supply chain and new suppliers may increase the risk score due to the lack of information, a possible financial restriction or low level of technological knowledge.
3) To reduce the supply chain – this could lead to a price reduction with the supplier but may affect the on-time delivery, due to high product demand and low production capacity.
4) To have a supplier ranking process based on quality performance – which could define in a set of suppliers those that are more critical and should be the focus of the current SQM team at that time.

Bruno et al. (2009) assert that the performance analysis and measurement of a set of suppliers to rank and select them for improving the competitiveness of the whole supply system shall be performed. As many conflicting factors should be considered in the analysis, the problem can be tackled using multi-criteria models and methods.

Based on this statement and option 4 above, the supplier ranking process is the best candidate for most of the companies, considering that no investments in manpower or the supply chain are necessary. This option also has a low cost for the implementation.

However, the problem is **how to calculate the risk of a worldwide and complex supply chain based on the quality performance analysis to rank and select them for improving the competitiveness of the whole supply system?**

1.3 Research Questions

In order to answer the question presented in section 1.2, it was necessary to execute a Systematic Literature Review (SLR) to identify what are the methods proposed for SQM and how they have been performed in the industry. Thus, this seeks aimed to verify if any method proposed in the literature could be implemented or adapted in the aerospace company considered in this work. The first research question was defined as:

(RQ1) What are the main methods for supplier quality management proposed in the literature?

Besides the verification on which methods have been used in the SQM, a specific check for the risk analysis method was done. This method has been applied in the most of companies, in special in the aerospace companies due to the quality management systems requirement defined in the International Quality Standard AS9100, that requires the company to have actions to address risk and opportunities that need to be determined to prevent or reduce the undesired effects (IAQG, 2016). Considering this and also that any product or process change may bring risk to the business, the second research question is:

(RQ2) - How the risk assessment has been taken into consideration?

With these two questions, the goal is to provide at the end of this work, a proposal for the aerospace company to calculate the risk of a set of suppliers resulting in an indication of which one shall have special attention based on the quality performance history or any other data necessary.

1.4 Objectives

The main goal of this work is to use the logistic regression method to calculate the risk of a supply chain from an aerospace company. The purpose of risk analysis is not excluding any supplier from the improvement tasks or obligations but to provide a start point for improvements and corrections with them.

Three specific objectives were defined:

1) To verify how the risk analysis has been performed in the literature and how they are improving the supplier quality performance.
2) To apply the logistic regression method to calculate the risk from a set of suppliers.
3) To analyze the results obtained from the logistic regression and from current method applied by the aerospace company.

1.5 Organization of the Text

This work is structured in five chapters. Chapter one consists of the introduction with the objectives and the organization of the work.

The second chapter provides the bibliographic review, with a systematic literature review performed to verify what are the main methods for supplier quality management available in the literature and how the risk assessment is considered in the SQM. In the theoretical foundation section, it is explained the concepts for supply chain management, supplier quality management, risk and logistic regression.

The third chapter provides the methodology proposed to assess the risk analysis of a supply chain using logistic regression model.

The fourth chapter presents the discussion on the results from the risk calculated with the new method and in the fifth chapter, the conclusion, suggestion for future works and restrictions.

Chapter 2

BIBLIOGRAPHICAL REVIEW

In order to contribute to a better understanding of this work proposal, this chapter presents the theoretical foundation and the systematic literature review executed.

2.1 Theoretical Foundation

This section aims to explain the theory of supplier chain management which includes the supplier quality management process, the concept of risk and the logistic regression analysis.

2.1.1 Supply chain management

Supply Chain Management (SCM) means to manage all the activities involved in delivering a product from raw material through to the customer including sourcing raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels, delivery to the customer, and the information systems necessary to monitor all of these activities. All these activities are coordinated and integrated by the supply chain management team in a seamless process.

Firms can no longer effectively compete in isolation of their suppliers and other entities in the supply chain. Interest in the concept of supply chain management has steadily increased since the 1980s when companies saw the benefits of collaborative relationships within and beyond their own organization. Companies have become more specialized and search for suppliers who can provide low cost, quality materials rather than own their source of supply.

It became critical for companies to manage the entire network of suppliers to optimize overall performance. These organizations have realized that whenever a company deals with another company that performs the next phase of the supply chain, both stand to benefit from the other's success (Lummus, Vokurka, 1999).

Hassini (2008) complements that SCM aims to execute management that drives to maximize the surplus that results from the difference of the price paid by the customer and with all the operational costs accumulated throughout the supply chain.

For a company to get a competitive advantage in the market, it is necessary for it to be part of an efficient supply chain. Simchi-Levi et al. (2000) defined the SCM as a set of approaches used to efficiently integrate suppliers, manufacturers, warehouse and stores for the merchandise be produced and distributed at the right quantities, at the right location and at the right time in order to minimize system wide costs while satisfying service-level requirements.

The SCM shall not be considered strictly in the management of the first tier of suppliers, but shall be considered in the management of the whole process: all sub-tiers, the warehouses and distribution centers and finally the customers, as shown in Figure 2-1. The main goal of the SCM is taking care of the efficiency in the production, distribution and the management of the costs.

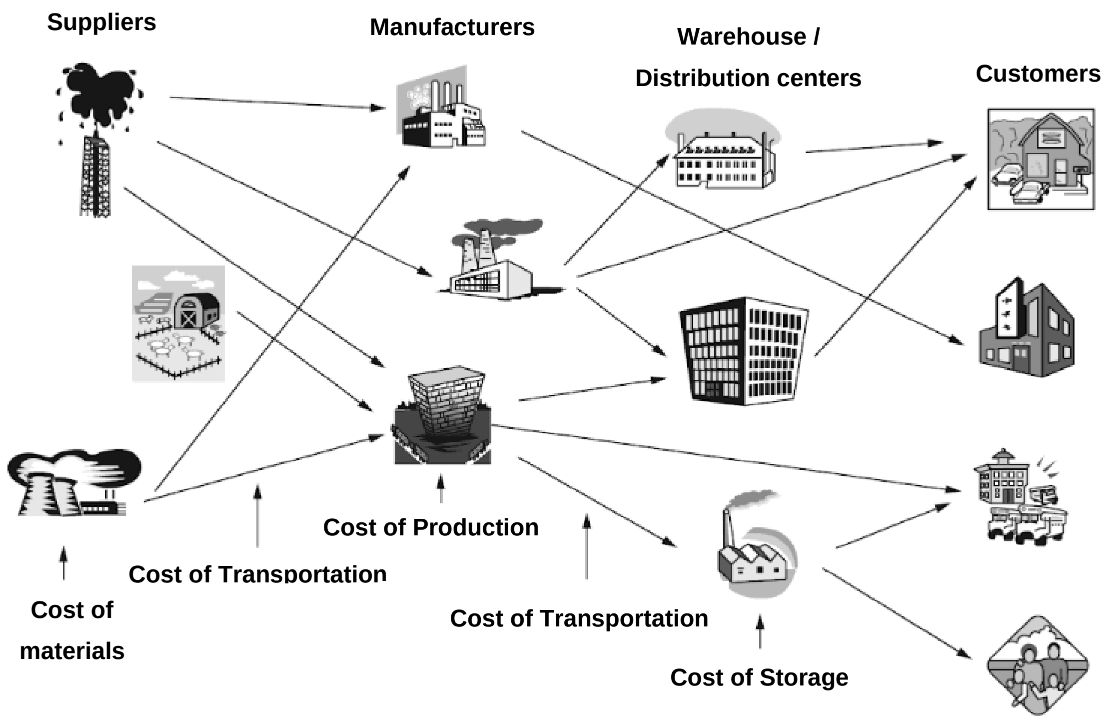

Figure 2-1 - The logistics network managed by SCM as defined by Simchi-Levi et al. (2000).

Lummus and Vokurka (1999) explain that a key point in supply chain management is that the entire process must be viewed as one system. Any inefficiencies incurred across the supply chain (suppliers, manufacturing plants, warehouses, customers, etc.) must be assessed to determine the true capabilities of the process. Figure 2-2 describes the total integration required within the supply chain.

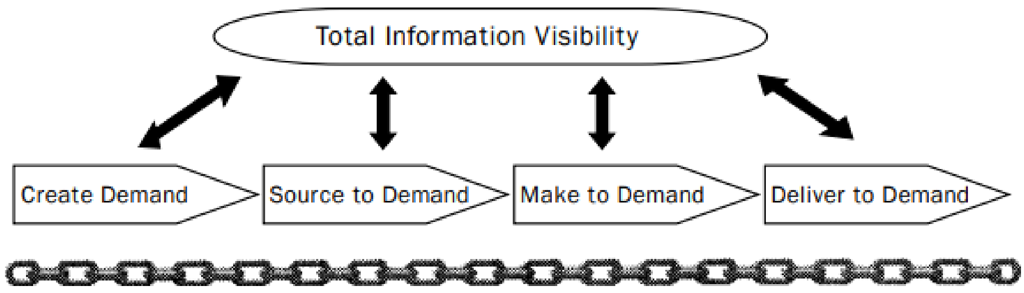

Figure 2-2 – Supply chain integration defined by Lummus and Vokurka (1999).

Simchi-Levi et al. (2000) assert that there are three points that impact the SCM:

1) The supply chain strategy cannot be defined without the participation of other departments. It shall be aligned with the development chain of the company (see the relationship
2) Figure 2-3) and also aligned with the specific goals from the organization, for example the strategy to increase the profit or market share.
3) The challenge to project and runs the operation with the whole supply chain aiming the cost reduction and keeping a good service level.
4) Uncertainty and risks are present in the whole process at all the time. The customer order demand cannot be considered as a final number, the transportation process may have problems leading to delays, machines may break and the manpower demands investment in training, good salary and capable people. The risk analysis shall be a process of SCM.

Fawcett et al. *(*2008) complement that the resisting forces to strategic supply management come both from the nature of the organization itself and the people that compose the organization. Some barriers include internal and external turf protection, poor collaboration among chain partners, and lack of partner trust. If SCM is to be implemented across company borders, a revamp in attitude and thinking is necessary and once the barriers to successful SCM are identified, bridges can be designed and implemented to attain desired benefits.

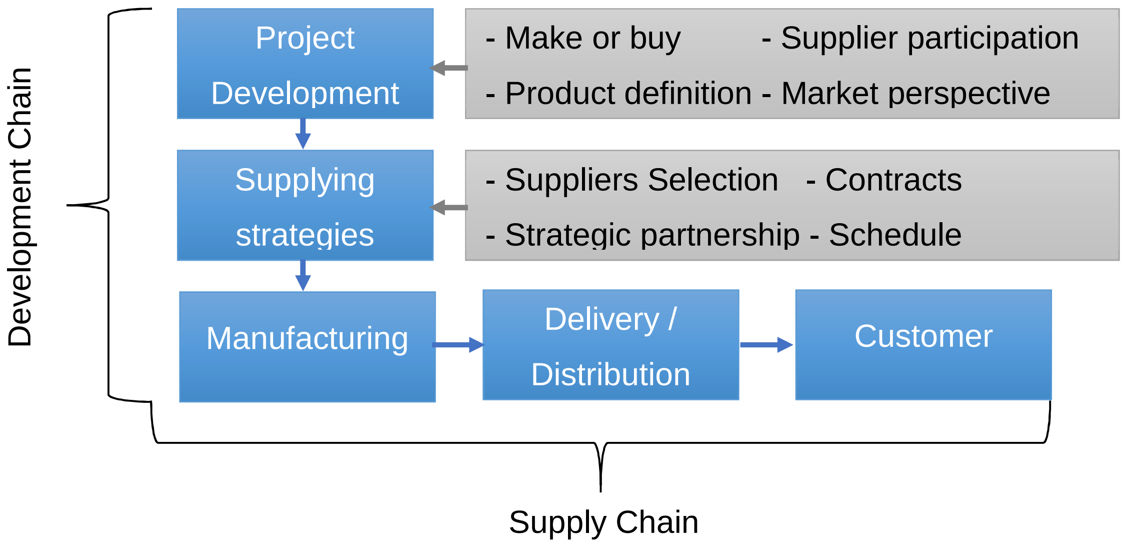

Figure 2-3 – Integration between development and SCM adapted from Simchi-Levi et al. (2000).

2.1.2 Supplier quality management

The Supplier Quality Management (SQM) is defined by Foster Jr. (2008) as a systems-based approach to performance improvement that leverage opportunities created by upstream and downstream linkages with suppliers and customers. Lin et al. (2005) complement that quality and operational efficiency are known as the two greatest supply chain challenges and must be resolved to have a high-quality supply chain.

Inside the SCM, it's necessary – but not mandatory – to have an area dedicated for suppliers quality management which should be concerned with the sourcing, evaluation and selection of suppliers, provision of education and training, monitoring of supplier performance, and supplier certification (Yeung and Chin, 2004).

Fernandes et al. (2017) state that the SCM extends the concept of integrated management to all organizations involved in the process, from suppliers of raw materials to end customers. The growing competition, globalization of economies and the need to increase the competitiveness of organizations through operational efficiency, promote new opportunities and challenges in the management and organization of the entire supply chain. Thus, SCM appears as an essential tool for competitive advantage in the market, since it allows the development of a link between the market, the distribution network, the production process and procurement activities, offering to customers a service of excellence at a low cost.

Likewise, the Quality Management (QM) is another concept that promotes the competitiveness of organizations. Considering that customers are becoming more demanding, they are increasingly looking for companies that meet their needs in terms of products/ services, and companies that can indeed outweigh their expectations. Thus, QM influences the performance of companies and customer satisfaction, as well as other stakeholders.

Supplier Quality Management (SQM) can also be defined as a combination of Total Quality Management (TQM) and Supply Chain Management but Vanichchinchai and Igel (2009) state that TQM and SCM have different starting points and primary goals, which can complicate an integrated implementation. However, they have evolved in similar ways to reach the same ultimate goal: customer satisfaction. TQM emphasizes internal (employee) participation and SCM focuses on external (business partners) partnerships but there is a need to emphasize both internal and external partnerships to further strengthen the emphasis on “total” TQM and the entire supply chain in SCM.

The importance of SQM into the organization process is explained by Forker (1996) after performed a survey with 348 aerospace component manufacturers and provided, based on the results, new insights into factors that affect supplier quality performance, which can be measured by performance, features, reliability, conformance, durability, and serviceability. This work highlights the importance of the supplier implements quality tools in the production to contribute to better development.

Chang et al. (2009) proposed a model for quality management, shown in Figure 2-4, which explain how the SQM shall be executed in a multilevel supply chain splitting this into four parts:

1. The basic environment of quality management. The environment of multi-suppliers quality management for the aerospace product includes the quality culture, the criterion system, the information security, the organization framework, the network condition and the society environment.
2. The product quality transfer process. The whole product is composed of systems, the system is composed of components, and the component is composed of parts and material. The quality information streams from the lower level supplier to the higher supplier in the product forming process.
3. The quality management of aerospace product developing process. Aimed at the particular aerospace product developing process, the quality management can be divided into four periods: the quality prediction, development process quality management and control, Quality Problem Tracing and the quality date analysis and decision
4. The object of quality management. “No Defect” is the object of aerospace product quality management, all technical work and management should be done well in one time. And all the periods, parts, operations in the developing, manufacturing and service period should be precise.

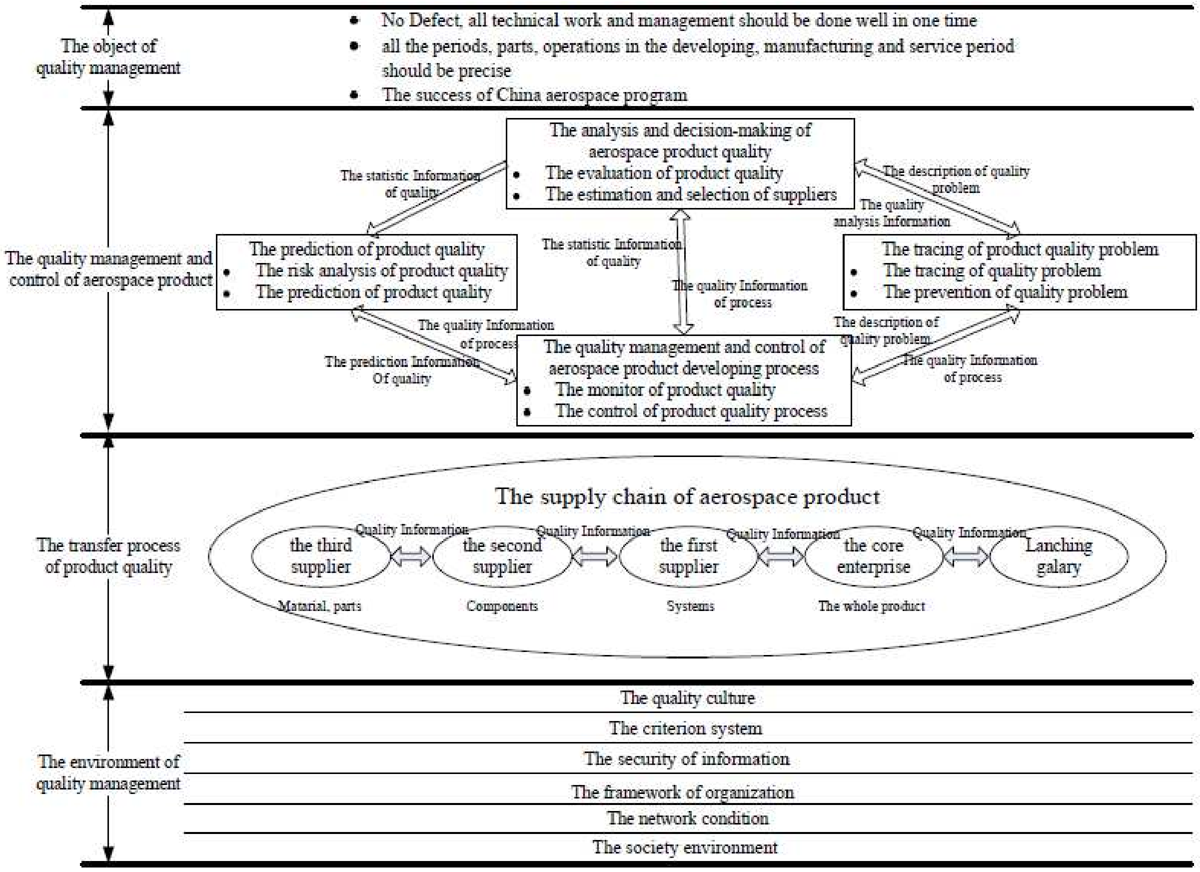

Figure 2-4 – The quality management mode of aerospace product with multilevel suppliers proposed by Chang et al. (**2009**).

The SQM activities should be guided by the 3 management process defined by Demian Juran (quality guru) and explained by Marshall Junior et al. (2008):

Quality Planning – is the preparation process to obtain the objectives. It is a set of activities that aims to develop products and process necessary to attend the customer needs and involve the following steps:

- To identify the customers.
- To determine customer needs.
- To define the product characteristics that attend customer's expectations.
- To create a process capable to reproduce these characteristics.
- To train the employees for the plan adherence.

Quality control – is the process to assure the execution of the process and achievement of the objectives defined in the planning phase and involve the following steps:

- To analyze the performance.
- To compare the performance with the targets.
- To start from the differences.

Quality improvement – is the process to assembly products in a high-level execution. It aims to elevate the results to a new level of performance, in the incremental state (continuous improvement) or innovation state (drastic improvement) and involve the following steps:

- To define the necessary infrastructure to guarantee a constant improvement.
- To identify the specific needs to create improvement projects.
- To define a group of people and define each responsibility to make it a success.
- To supply the resources and training necessary to the team to find out the causes, to stimulate the solution and to implement controls to keep the good results.

The SQM responsibility is also to focus on the quality improvement not only at the supplier side, but into the organization. As according to Marshall Junior et al. (2008), the quality culture expected into the organization shall be defined based on the following 4 points and in the 14 steps defined by Philip Crosby (guru of quality):

1. The quality is defined as the requirement conformity.
2. The system drives the quality of prevention.
3. The standard execution is the zero defect.
4. The quality measurement is the cost of non-quality.

And the 14 steps are:

1. Commitment to quality (high management level).
2. Group of quality improvement.
3. Measurement (to define standards).
4. Cost of non-quality.
5. Conscience.
6. Corrective action.

7. Zero defect planning.
8. Employee training.
9. Zero defect day.
10. Target definition.
11. Removal of the root cause.
12. Identification.
13. Quality advice.
14. Make all it again.

2.1.3 Risk

This section presents the concepts of risk definition, risk management and risk prediction.

2.1.3.1 Risk definition

There are different types of risks and it can be divided by steps, however, it is necessary to first understand what is the risk meaning. According to Bernstein (1997), the word risk comes from old Italian *risicare* and means dare and follows the uncertainty and the word risk can be interpreted as the set of uncertainties that it is found when trying to do something.

The risk does not necessarily need to be something negative. There are some situations in which the risk can be positive. As according to PMI (2013), risk is an uncertainty event or condition that if happen, it will cause a positive or negative effect on the project objectives and a management shall be performed to identify, to analyze, to develop answers and to monitor the risks with the aims to reduce the probability and impact in the negative events and to increase the probability and impact in the positive events. The terms positive and negative can also be referred to as opportunities and threats.

Salles Jr et al. (2006) complement that every risk has three components:

1. The event itself, where shall be identified the root cause of the risk and also the effect (or consequence).
2. A probability associated.
3. An impact on the project.

In these three components, it can be seen that the probability is directly linked to the cause, and the effect is linked with the impact. This means that if an action is taken in the cause of the risk, it may impact the probability of the risk happen. If action is taken in the effect of the risk, it will change the impact.

2.1.3.2 Risk management

In risk management, it’s necessary to identify the uncertainties and try to control them. Hallikas et al. (2004) proposed a process of 4 steps for risk management:

1. Risk identification.
2. Risk assessment.
3. The decision and implementation of risk management actions. In this case, there is a possibility to transfer, takes, eliminate, reduce the risk and in some cases perform analysis of individual risks.
4. Risk monitoring.

Kırılmaz and Erol (2017) defined also risk management in five steps:

1. Risk identification.
2. Risk measurement.
3. Risk evaluation.
4. Risk mitigation.
5. Risk monitoring and control.

Hallikas et al. (2005) combined in the risk management approach, the relationship with suppliers considering that the collaboration could be seen as a means of managing and reducing risks, but it also introduces some new risk factors. Hallikas et al. (2004) demonstrated what are the challenges that network co-operation brings to risk management and proposed a method for risk management in a complex network environment. As per research questions, the authors intended to identify the main root causes which contribute to start or increase the risk on a supplier chain management and proposed a process consisting in risk identification, risk assessment, decision and implementation of risk management actions and risk monitoring.

Baxter K and Baxter R (2019) state that should a risk turn into an issue, it will be more time consuming and costly to recover from than the original risk, had it been mitigated and proposed a risk management plan with it benefits and a process to implemented it as follow:

Risk management plan:

- New strategies are being executed.
- Cultural change initiatives are being implemented.
- Projects result in new process, products or services.
- Initiatives impact safety, quality or customer service.
- Projects or initiatives are large, complex and costly.

The benefits of a risk management plan include:

- Increased focus and attention on risks.
- Proactive approach for preventing risks from becoming issues.
- A consistent approach for analyzing, prioritizing, communicating and managing risks.
- An approach to efficiently and effectively mitigate risks.
- Cost reduction and time savings by identifying, prioritizing and managing risks.

The process for the risk management plan are:

1. Risks are identified during the project or initiative lifecycle; inputs to the risk management plan may include charter, schedule, stakeholder plan, resource plan, quality plan, issue plan, change control plan, communication plan and training plan.
2. Risks are logged with date identified, description, probability and impact.
3. Team assess and prioritizes risks based on probability and impact to scope, schedule and budget.
4. Team determines type of response (accept, avoid, reduce, transfer) and response plan to mitigate the risk.
5. Team monitors and controls risks via the response plan.
6. Process is repeated when additional risks are identified.

Sawik (2011, 2014) proposed a method to integrate supplier selection, order quantity and customer orders based on disruption risk management in an out-sourcing scenario. While the supplier selection is considered to be a long-term strategic decision, the order quantity allocation and customer order scheduling are short-to-medium-term tactical decisions. In particular, in a make-to-order manufacturing, all the above decisions can be made for a short-to-medium-term planning horizon. Given a set of certified part suppliers, the medium-term supply portfolio determines an allocation of demand for parts among a subset of the selected suppliers and simultaneously, for each disruption scenario, an assignment of customer orders to periods over the planning horizon is found.

Walter et al. (2003) conceptualized the importance of the relationship between supplier-customer which in a long-term contributes for a stronger competitive position in the market. To develop a good relationship with suppliers, the customer must be able to recognize some important difference between them, and on the supplier side, they need be trustful and provide cost reduction, quality, volume, and safeguard. Besides, Lai et al. (2005) explored the link between relationship stability and supplier commitment to quality.

The risks can have different ways to be calculated, however, if there is no data available to be used on this calculation, it may be difficult to predict or solve the problems related to risk. Based on this concern, Pinto et al. (2013) developed a distribution-free model tool to be used when only a limited and perhaps unstructured base of data is available. The computational model aims at creating a solid foundation for developing a comprehensive human-in-the-loop decision support system. Humans with in-depth knowledge of a particular domain, capable of reviewing the decisions made by the computational model are necessary to verify the consistency of the results.

For risk management in projects, Salles Jr et al. (2006) proposed a spectrum to show and guide the project managers to keep the risk under control and mapped covering part of uncertainties, but not the totality, as according to Figure 2-5.

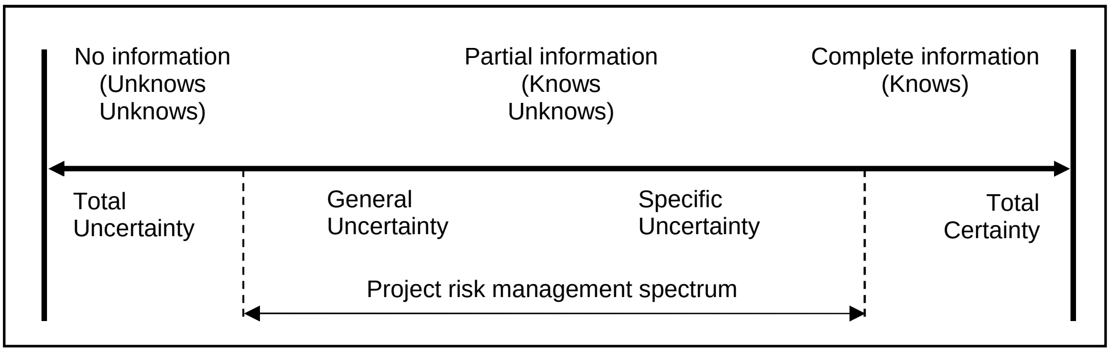

Figure 2-5 – Spectrum for risk management proposed by (Salles Jr et al., 2006).

2.1.3.3 Risk prediction

Considering the in a scenario may have a lot of uncertainties and it is necessary to take over the control of the situation, the risk prediction is necessary.

For the risk prediction, Salles Jr et al. (2006) defined three scenarios:

1. First when all the information necessary about something is available and it is sure about it, so in this case, cannot be classified it as a risk.
2. The second is when there is partial information about something and it is not sure, so risk is probable.
3. The third scenario is when there is no information about something, there is a risk.

PMI (2013) complement that the risk can be positive or negative. For the negative impact or threats in the project, four strategies that can be applied: Prevention, Transferring, Mitigation and Acceptance. In the prevention, expects that when there is a partial information some actions shall be done. In the transferring strategy, the risk could be moved to third part in the project however the risk consequences shall be planned. In the mitigation strategy, it is expected that the risk shall have its probability and impact reduced. In the acceptance, the risk is expected and accepted, however any action will not be taken unless is necessary.

For the positive impact or opportunities in the project, four strategies can be applied: Exploration, Improvement, Sharing and Acceptance. In the exploration strategy, it is necessary to explore the risks to guarantee that the opportunity will happen. In the improvement, the strategy shall to improve the opportunity to happen in a better way, which would bring benefits to the project. In the sharing strategy, the intention is to share the risk with a third part which may have better capability to explore the opportunity. In the acceptance strategy, the intention is to appropriate the opportunity when it happens, but not seek this actively.

The risk assessment is one of many tools available to predict the risk. Additional tools are the usage of Malcolm Baldrige National Quality, the elaboration of supplier interlock matrices, the execution of audits in the supplier's facility and also to apply the SWOT analysis.

As according to Dyson (2004), SWOT analysis aims to identify the strengths and weaknesses of an organization and the opportunities and threats in the environment. Having identified these factors strategies are developed which may build on the strengths, eliminate the weaknesses, exploit the opportunities or counter the threats. The strengths and weaknesses are identified by an internal appraisal of the organization and the opportunities and threats by an external appraisal. The Figure 2-6 shows how to build a SWOT analysis.

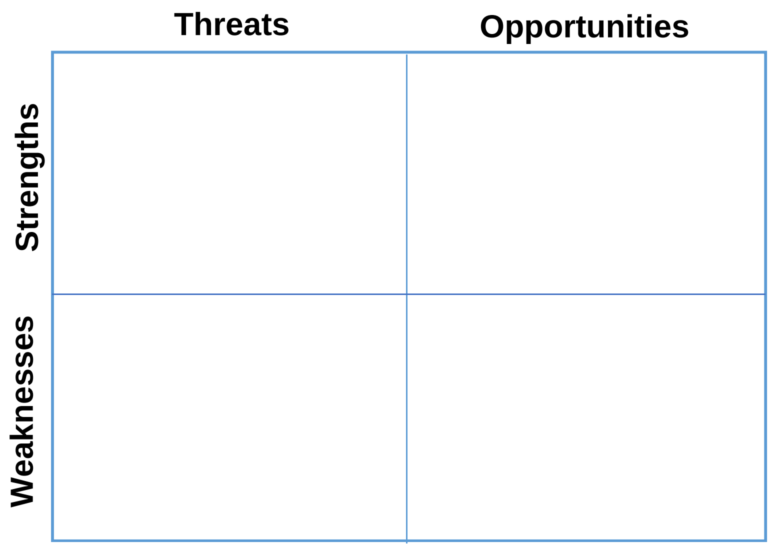

Figure 2-6 – SWOT Analysis model.

Another predictive tool that can be applied to the reduction of supplier's risks is the Lean Manufacturing concept. Guo and Xu (2007) proposed a model of Lean Supplier Management between OEM and its suppliers with the aim to eliminate wastes, a cost reduction and continuous improvement through supplier's categorization, the design of a supplier quality assessment and creation of an index system of supplier performance evaluation.

Zsidisin et al. (2004) state that purchasing organizations are exposed to risk in their interactions with suppliers, whether it is recognized and managed, addressed in a cursory manner or altogether ignored. In order to understand the supply risks that exist, purchasing organizations can proactively assess the probability and impact of supply risk in advance, or reactively discover risk after a detrimental event occurs.

2.1.3.4 The critical factors in the risk evaluation

For the risk calculation, it is necessary to define the variables that will be applied. For a cash loan example, the bank need to perform a risk assessment and for this, to consider some variables such as cash loan history, occupation, age and if the person has a job with a salary for example.

Any industry can also implement a risk evaluation. However, the choice of factors to be used in the risk analysis should be defined with attention to avoid deviation from the results.

Zsidisin et al. (2004) state that the risk assessment process shall measure eight factors, which are available in Table 2.1 with their respective definitions. These factors are deemed critical to have a reliable, predictable, cost-effective supply of materials and services.

Table 2.1 - Factors to be considered in the risk assessment.

Nº	Factor	Definition
1	Design	Ability to complete the design, follow design for manufacturing goals, validate the design, assess the interactions of the material, and manufacture the item. This refers to both company and supplier design as well as statements for work for service to outsourcing suppliers
2	Cost	Determined by target costs from the customer, industry benchmarking, should-cost models, and make-or-buy decisions where appropriate.
3	Legal	The risk associated with the substantive legal status of the material, product, or services, such as import/export restrictions and tax issues. Additional risk factors include legally enforceable restrictions or commitments relating to the use of the material, product, or service.
4	Availability	Assessing the risk of the sourcing, unit volume requirements, and the material tooling (where applicable).
5	Manufacturability	The risk associated with manufacturing's ability to produce when material specifications are met. If the material has not yet been received, this may entail anticipating potential future problems, such as materials that meet specifications but do not meet design for manufacturing.
6	Quality	The direct and indirect materials, service, or product consistently meets requirements, and supporting processes are in place to ensure control.
7	Supply base	Assessing and choosing suppliers of good financial health and manufacturing in politically stable or low-risk natural disaster areas. It also refers to instances when Semi becomes too large a percentage of a supplier's business, either through capacity or corporate revenue Risk.
8	Environmental, health and safety impact	Issues such as the handling and use of hazardous materials and compliance with EPA, OSHA, and other governmental agency policies by suppliers or firms.

In complement of these eight factors, Dickson (1966) proposed 23 factors that should be considered in the supplier selection activity (Table 2.2). Some of these factors (for example, price and financial position desire for business) were not considered in the proposed methodology since the purpose of this work was to obtain a statistical tool to calculate the supplier's risk focusing on the quality performance during the series production.

Table 2.2 – Factors to be considered in the supplier selection defined by Dickson (1966) as cited in Cheraghi et al. (2016).

Number	Variable
1	Quality
2	Delivery
3	Performance History
4	Warranties & Claims Policies
5	Production Facilities and Capacity
6	Price
7	Technical Capability
8	Financial Position
9	Procedural Compliance
10	Communication System
11	Reputation and Position in Industry
12	Desire for Business
13	Management and Organization
14	Operating Controls
15	Repair Service
16	Attitude
17	Impression
18	Packaging Ability
19	Labor Relations Record
20	Geographical Location
21	Amount of Past Business
22	Training Aids
23	Reciprocal Arrangements

2.1.3.5 Risk analysis performed by the aerospace company

The aerospace company used in this work as a case study considers or adopted some of the variables (factors) proposed in Table 2.1 and Table 2.2 in its risk analysis. The impact and vulnerability are also taken into consideration.

After the calculated risk, there is a committee responsible to evaluate the risk on each supplier and to drive the appropriate actions.

2.1.4 Logistic regression

The objective of logistic regression is to find the best fitting to describe the relationship between an outcome (dependent or response) binary variable and a set of independent (predictor or explanatory) variables (Hosmer and Lemeshow, 2000) and have been applied for risk prediction purposes. The application method is described in the Chapter 3.

In the financial sector, banks want to know if there will be a risk for lending money to the customer, or in the health area, the researchers want to predict the risk of launching a new medicine into the market. In the industry, there is a concern with the supply chain risks, which have a direct impact on the company strategy.

In product development, for example, the supply chain is one of the critical factors in the project. Fossas-Olalla et al. (2015) applied a logistic regression method to show that the technological collaboration with suppliers is an important factor in the innovation process and product launch. They found that suppliers have a great experience and knowledge about key components for new products development, can contribute with ideas for solving technical problems in manufacturing, and can share or avoid the risks, costs, and benefits in the product innovation and development.

Logistic regression was also applied by Genis-Gruber and Öğüt (2014) to investigate how the industry innovation capability is affected by suppliers and customers. As customers and suppliers distance increases, the industry is more likely to develop and innovate. From the customer and supplier side, there is a risk associated.

Before to the partnership with suppliers, it is necessary to select them. Sluis and De Giovanni (2016) investigated through an empirical study the key drivers for a supplier selection, applying the logistic regression method. This study identified the risk of supplier selection based on the supplier performance level, supply chain orientation and the degree of supplier integration.

2.2 Systematic literature review

In order to answer how to execute and have a good SQM, an SLR was conducted based on the research methodology adopted from Kitchenham (2004); Budgen and Brereton (2006). Figure 2-7 shows the research methodology adopted with the steps described in the next sections. The motivation for the review (Step 1 of Figure 2-7) was presented in section 1.2, and two research questions (Step 2 of Figure 2-7), available in Table 2.3, were proposed to contribute to the research.

Table 2.3. Research questions for SLR

ID	Research Question	Objective
RQ1	What are the main methods for supplier quality management proposed in the literature?	To seek and identify what are the methods proposed for SQM
RQ2	How the risk assessment has been taken into consideration?	To identify if the risk methodology has been proposed for SQM and for which conditions it could be applicable

To verify whether any similar SLR had been conducted, a search was performed at EBSCOhost, Compendex and Google Scholar digital libraries using the following string within the titles, abstracts, keywords, and text:

(supplier AND quality AND literature review) OR (supplier AND management AND literature review).

Most of the works found were related to supplier selection or Total Quality Management, which covers everything related to quality. None of them were directly related to the SLR on SQM and could not answer, in the same work, all the research questions.

The motivation to execute an SRL started with the problem presented in section 1.2. Some companies which have complex products with different technologies and shall deal with hundreds of worldwide suppliers requires to have an effective SQM and to work on risk mitigation with them Hallikas et al. (2005). The purpose is to map all methods proposed by the literature and to verify which one could be implemented or adapted in the aerospace company supply chain management.

The RQ1 was created based on the SLR performed by Pfohl et al (2010) to provide an overview of existing publications and studies concerning Supply Chain Risk Management and its relevance to the industry and suppliers management based on risk proposed by Ojala and Hallikas (2006); Levary (2008); Costantino and Pellegrino (2010); Wu et al. (2010). How the risk (assessment) has been discussed and applied in the Supply Chain Management could be adjusted to be used in the SQM.

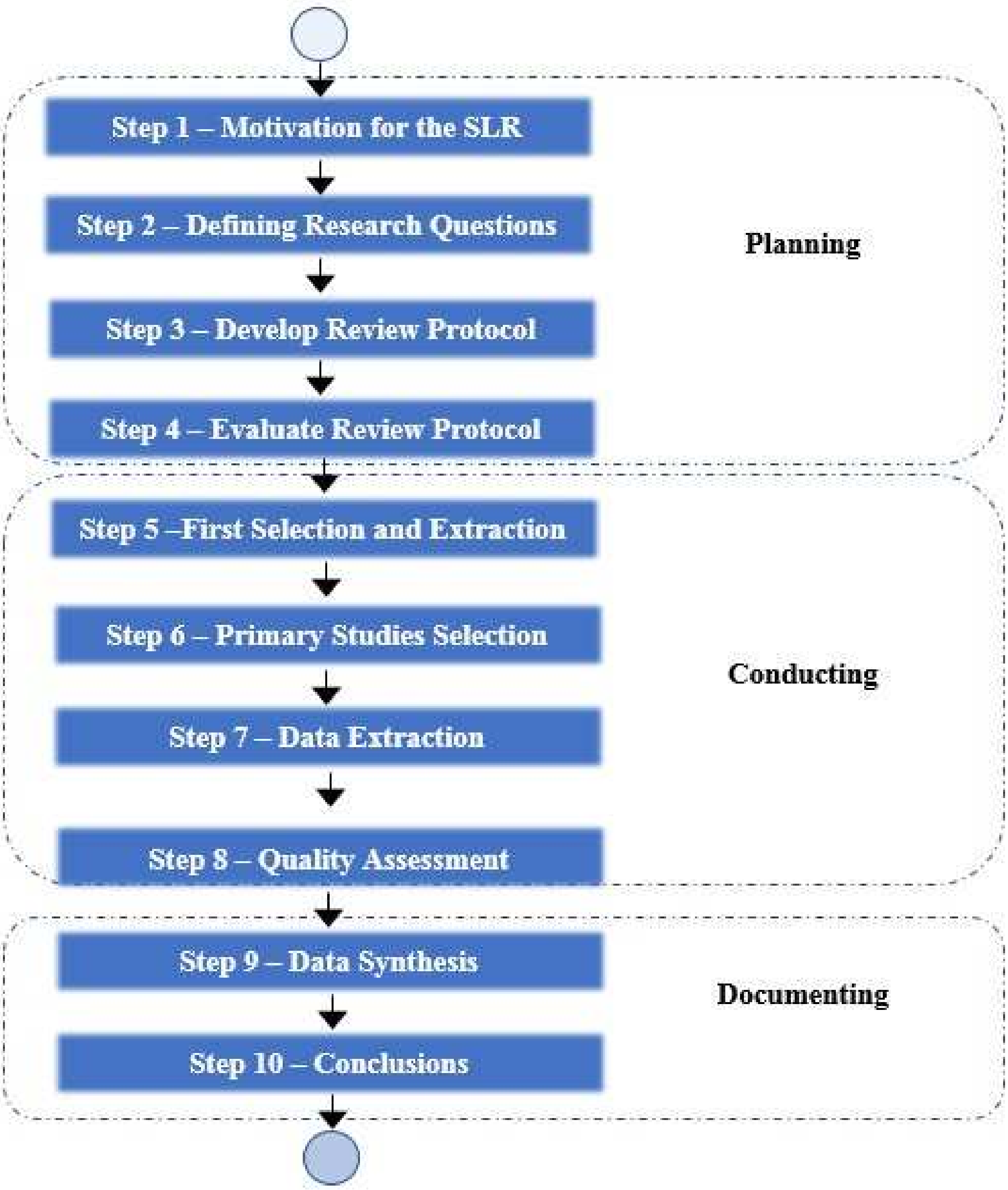

Figure 2-7 – Systematic steps adopted from Kitchenham (2004); Budgen and Brereton (2006); Martins and Gorschek (2016).

2.2.1 Search strategy

For the identification of papers, the search strategy of Figure 2-8 used in this work was adapted from Colicchia and Strozzi (2012). The search string used the keywords extracted from the research questions in order to contribute to the research to find out works related to SQM, however the keywords defined for the search demanded some tryouts on all databases used in this research – Science Direct, IEEE Xplore and Springer Link – due to the number of papers related to supplier management and supplier risk available in the literature.

After some tryouts using different combinations of words (such as sub-tier, quality, management, risk, and quality tool), it was defined that the search should be proposed considering only the titles of the papers (only at Science Direct and IEEE Xplore base) and in all field in the Industrial and Production Engineering at Springer Link, otherwise the number of papers not related to SQM would remain to be captured. The search string used in the SLR is specified below:

“Supplier Quality” OR “Supplier Risk”

The reason to consider Supplier Quality at the search string was to verify besides supplier management, how the quality is important in the industry and how it has been conducted. Supplier risk was considered in the search string in order to verify in terms of risk analysis/assessment, how the quality performance has been impacted and is taken into consideration.

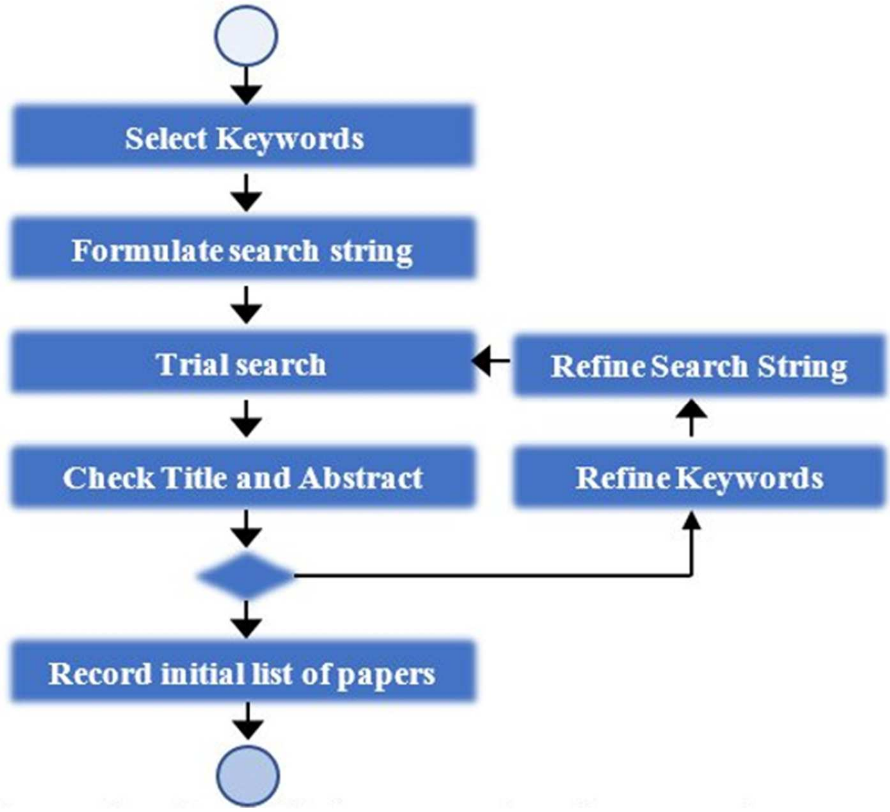

Figure 2-8 – Systematic steps adopted from Kitchenham (2004); Budgen and Brereton (2006).

2.2.2 Review protocol

A review protocol was developed (Step 3 of Figure 2-7) with the main elements as follows: the **selected databases** chosen were Science Direct, IEE Xplore and Springer Link; the **search method** was preliminarily defined on research through web search engines available on digital libraries, however during the search, it was necessary to refine the search depending on the database (for Springer Link, it was necessary to execute the search considering Industrial and Production Engineering field); the **population** was considered only peer-reviewed publications reporting methodologies for supplier quality management; the purpose of the **intervention** was to verify how methods were being used and validated in different industries; the **outcomes** shall provide the main methods available.

As studies selection criteria, it was determined that papers should be scientific articles from journals, conferences, magazines, symposium and book chapters. Only articles written in Portuguese and English were considered. The **inclusion criteria** were defined to be primary studies, studies from any period (no date limit would be set), studies presenting methods for SQM, studies that present methods for risk assessment and its calculation, studies in which the cost of non-quality was taken into consideration, and studies with innovative methods. On the **exclusion criteria** (not considered) were secondary studies, non-Portuguese or non-English written papers, duplicated studies, articles proposing methods for supplier management in terms of non-Portuguese or non-English written papers, articles proposing methods for supplier management in terms of relationship-contract and studies for accounting approaches.

In order to validate the protocol review (Step 4 of Figure 2-7), a trial with one of the participants from the SLR was performed, which defined a set of five articles with a high number of citations and could be considered in the SLR, and another five which could not be considered in the SLR. The same papers were provided to another participant in order to inform which one could (or could not) be considered in the SLR, resulting a 90% agreement.

2.2.3 Procedure for studies selection

The primary studies were selected according to Figure 2-9. The search string used was provided in sub-section 2.2.1. The search string was primarily applied on titles in the two databases considered for the research (Science Direct and IEEE Xplore) and were captured a total of 196 articles (Step 5 of Figure 2-7). On the Springer Link database, the search string applied in all the search fields in the Industrial and Production Engineering database, otherwise the number of articles related to the supply chain would be mixed with SQM resulting in duplicated articles.

After running the search based in Figure 2-9 and applying the inclusion criteria, we selected 135 articles (available in Appendix 1) for the data extraction (Step 6 of Figure 2-7). As the main purpose was to verify different and innovative methodologies for SQM, the three databases were selected in order to get the advantage of different areas they have and seek new methodologies never applied in the aerospace company.

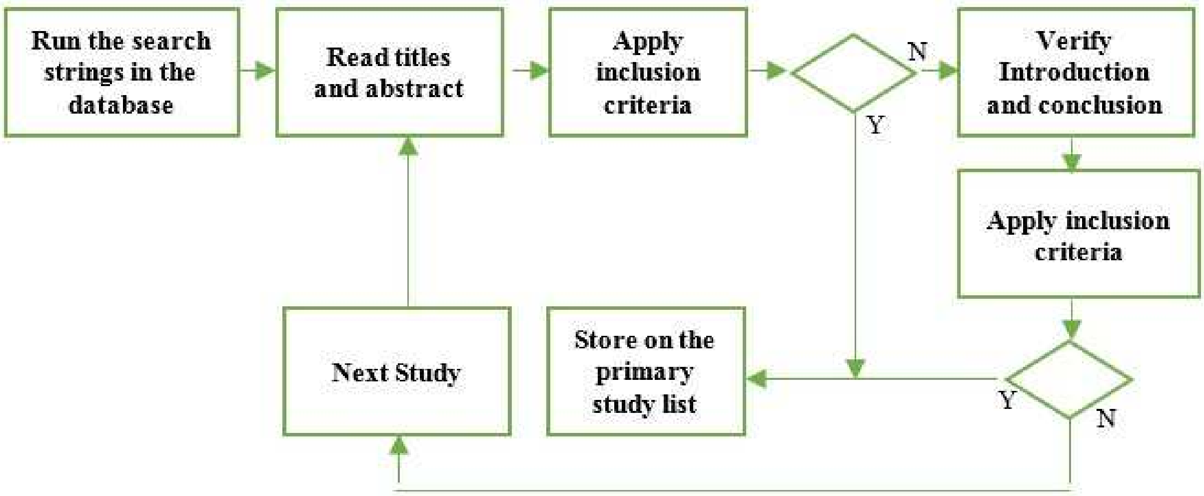

Figure 2-9 – Procedure for primary studies selection (Step 6 of Figure 2-7).

2.2.4 Data extraction

The first trial resulted in 196 articles divided as follows: 107 articles from Science Direct, 45 from IEEE Xplore and 44 from Springer Link database. In order to avoid executing the data extraction (Step 7 of Figure 2-7) for articles without correlation to SQM, the steps from Figure 2-9 were applied resulting in a reduction of 135 articles.

From the 61 articles not considered, 26 did not answer RQ1 and/or RQ2, 9 were proposing the same methods (duplicated), 6 were proposing methodology for second sourcing development, 6 were related to supply chain on Health area, 5 were news from magazines, 3 were discussing stock inventory, 3 were related to supplier maintenance and 3 were related to methods to define product sampling in order to define size of parts to be checked.

A database was built to get all the information necessary for this work. The information extracted is shown in Table 2.4.

Table 2.4 – Information extracted.

Title	Is this text applicable for my resource question?	Article proposal	Key words	Number of citations	Source of publication	Type of article
Article Source	Year of publication	Author	Volume	City	Country	Access Date
Address (DOI)	Area of industry	Application context	Research type	Main method	Method description	Does provide quality tools?
Techniques used for method implementation	Do they answer the research questions?	Are the methods clearly defined?	Is there a guideline for supplier's management?	Evaluation method	Any statistic method applied?	

2.2.4.1 Research method

The studies were categorized according to the applied research method and were partially adopted from Bryman (2006) considering the following methods:

- **Case study:** Adopted from Baxter and Jack (2008) as a tool for investigation and a tentative to answer research questions as for example how and why something was created, implemented and validated on industries.
- **Experiment:** How the concepts or solutions were verified and implemented.
- **Survey:** Adopted from Fink (2013) as a system to collect data from peoples using interviews or questionnaires which may be analyzed, compared, or may give a tendency in the future.
- **Illustrative scenario:** Papers providing a method illustration that was never implemented nor was its applicability verified.
- **Conceptual analysis:** Any methodology proposed in the theory but never experimented. The conception was never validated.

- **Industry report:** Method proposal implemented in the industry providing feedback on its results.

Most of the reached papers were providing a case study, as according to Figure 2-10, in regards to SQM or supplier risk. It was evidenced that literature brings a different concept in terms of the relationship between OEM and suppliers if compared with a real situation presented in section 1 by an aerospace company, where the SQM is a responsibility of supplier quality team and by the literature, the SQM is handled between suppliers and buyers. Besides the 60 case studies found, 29 papers presented some experimentation on the proposed methods. It can be highlighted the number of papers that propose the usage of Fuzzy logic on the SQM or supplier development as proposed by Chan and Kumar (2007) and Wu et al. (2010). Another 17 papers provided any kind of survey mainly on the electronics industry. Others 16 papers provided a conceptual analysis without necessarily having implemented it, as the analysis was done by Ojala and Hallikas (2006) on risks that enterprises have faced in their partnership relationships in the area of investment decision- making. Industrial reports were provided in 8 articles, providing real situations as done by Yoo (2014) when identified the relationship between return policy and product quality decisions. Last, 5 articles proposed an illustrative scenario.

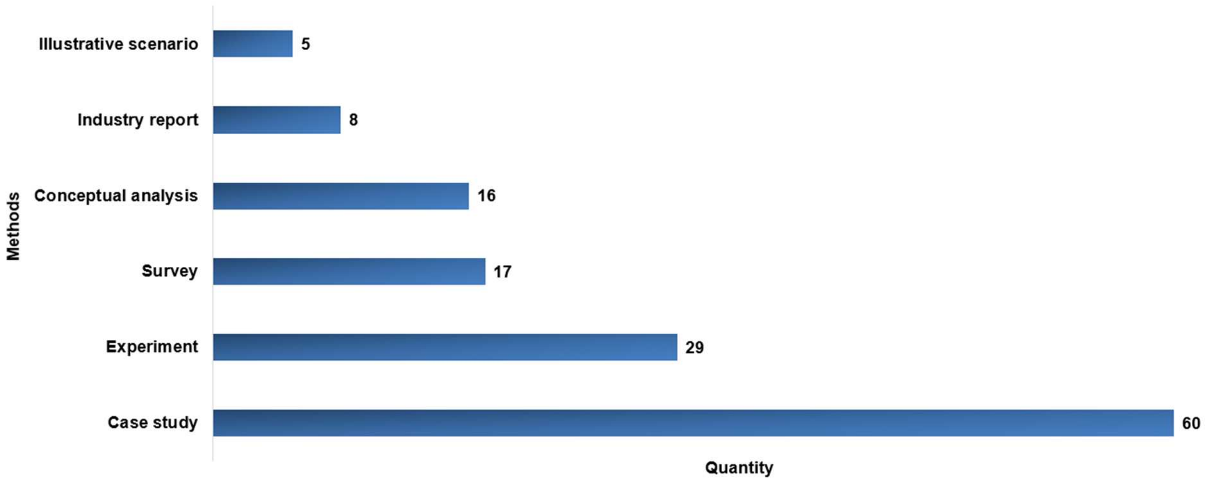

Figure 2-10 - Quantity of procedures for primary studies selection (Step 6 of Figure 2-7).

2.2.4.2 Context

On this SLR, those considered were papers related to industry, commerce and academic research. Most of the works found were done about to the industry, which justifies the case study and experiment as the top evaluation methods found.

2.2.5 Study quality assessment

In addition to search data execution, it is necessary to verify how good the information is. The study quality assessment (Step 8 of Figure 2-7) is important to assess the quality of primary studies, to guide the interpretation of findings and determine the strength of inferences and to guide recommendations for further research (Kitchenham, 2004).

In order to verify the quality and contribution level of articles found, a set of 3 questions was created (see Table 2.5) to classify the answer between Yes, Partially and No. The first question (QA1) verifies if the articles could answer most of the research questions. The Second question (QA2) aims to verify if the article's proposal could be easier understudied and the third question (QA3) focused mainly on guidelines for SQM. Based on the results, most of the articles have a significant contribution to SLR.

Table 2.5 - Study quality assessments results.

ID	Quality Assessment Questions	Yes	Partially	No
QA1	Is the aim of the study addressing the RQs?	120 (89%)	15 (11%)	0 (0%)
QA2	Is the presented approach clearly explained?	90 (67%)	45 (33%)	0 (0%)
QA3	Is there a clear guideline for Supplier Quality Management?	46 (34%)	89 (66%)	0 (0%)

2.2.6 Threats to validity

Publication bias refers to the problem that positive results are more likely to be published than negative results. The concept of positive or negative results sometimes depends on the viewpoint of the researcher (Kitchenham, 2004). To avoid a biased search, we carefully defined the inclusion and exclusion criteria during the protocol definition. Both were based on the research questions.

An exception was done in the Springer Link database, where the area of search was restricted to Industrial and Production engineering otherwise the number of papers not related to SQM would remain to be captured. To be more restricted, we considered only articles related to SQM, excluding any other relation between suppliers and commercial negotiation.

2.2.7 Results

To investigate how the SQM has been discussed in the literature and which methods they are proposing, an SLR was executed. The initial expectation with the SLR was to verify (or discover) a new concept of methodology which could be implemented to improve the SQM, however, from the 135 articles considered in the SLR, most of them do not provide a direct guideline for SQM (see QA3 in Table 2.5).

On the data analysis (Step 9 of Figure 2-7) performed, it was verified that in the literature there is a huge concern in a step before the SQM – the supplier selection. Even the aim of this SLR to verify methods for the supplier's management on the series production phase, in other words, management of quality performance of their products on the aerospace production line, the supplier selection methods proposed can contribute in some way on the SQM as well. Supplier selection can be considered as a multi-criteria decision-making and is one of the most important issues for firms Xiao et al. (2012). Furthermore, in the selection phase, the quality, purchase price, and costs need to be considerate to evaluate the supplier performance and take the decision to buy or not (Pi, Low, 2006).

To verify how the SQM has been discussed in the literature, as an inclusion criterion it was not defined the publication period (no date limit was set). As result, It can be observed in the highlighted area (in Figure 2-11) that SQM topics have been increased along the years as a consequence of how the companies' success depends on the interaction with their supply chain, processing materials or service to attend customer demands (Mentzer et al., 2001).

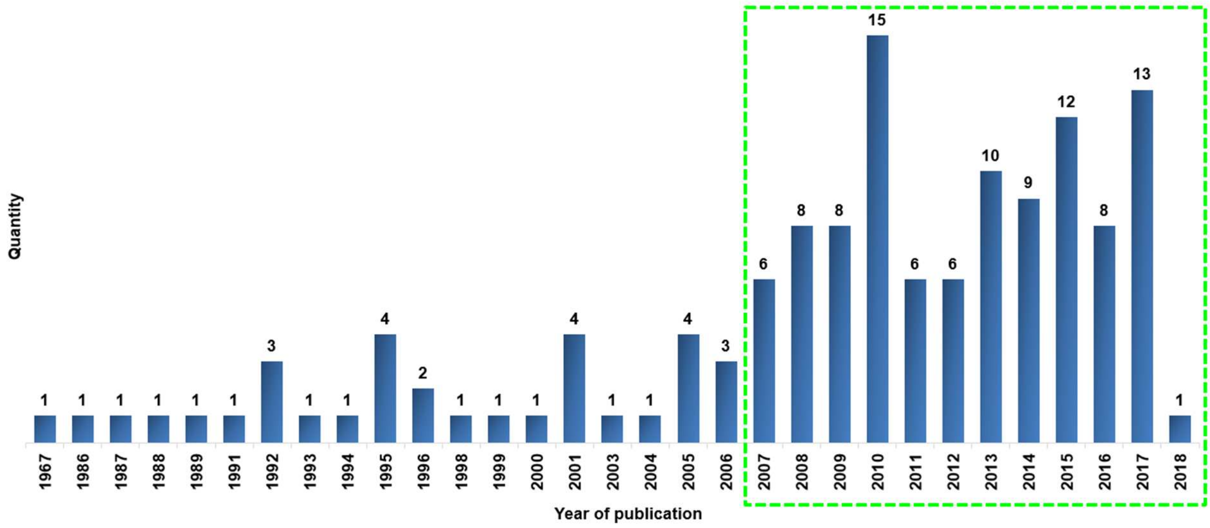

Figure 2-11 - Articles publication timeline for discussion on SQM.

Another explanation for the number raising in the last decade may have correlation with the Industry 4.0, where the increasing integration of the Internet of Everything and Big data into the industrial value chain has built the foundation for the next industrial revolution, although some companies insist to say that this is real and do not invest in this for a while Hermann et al. (2016). Moreover, as the manufacturers started a new strategy to develop goods with durability and quality to lease the service of a product instead of selling it to the customer Hawken et al. (2010), the suppliers become essential players to provide good parts with low costs.

The papers were also classified as according to (Figure 2-12) the criteria proposed by Vilela et al. (2016) as Solution proposed, with 81 papers (60% of total), Evaluation research with 27 papers (20% of total), Experience papers with 9 (7% of total), Illustrative scenario with 7 papers (5% of total), Validation research with 6 papers (4% of total) and Opinion paper with 5 papers (4% of total). The number of papers proposing any solution brings to a conclusion and a justification of the increased for the last 10 years (as explained in Figure 2-11). As the competitiveness results, innovation and transformation are necessary for the industries and this is not limited to the production area, but as well for the SQM, which needs to be constantly improved to get a product with high quality and low price from the supply chain.

Despite the number of papers with solution proposal, most of them did not provide a new solution, which means, an idea never implemented in the industry. It can be highlighted the number of papers with a method proposal for supplier selection, but none of them related to SQM dealing directly with non-conformances on the production line. For the Evaluation papers, 5 of them were proposing Risk Analysis to evaluate if the prioritization list of worst suppliers is correct or not, as argued by (Hallikas et al., 2005). For the Experience papers, (Song et al., 2014) investigated the issue that an aircraft manufacturer had with bad supplier management for batteries, which resulted in an aircraft with fire and all the fleet grounded up until investigations were completed. The remaining papers are related to TQM.

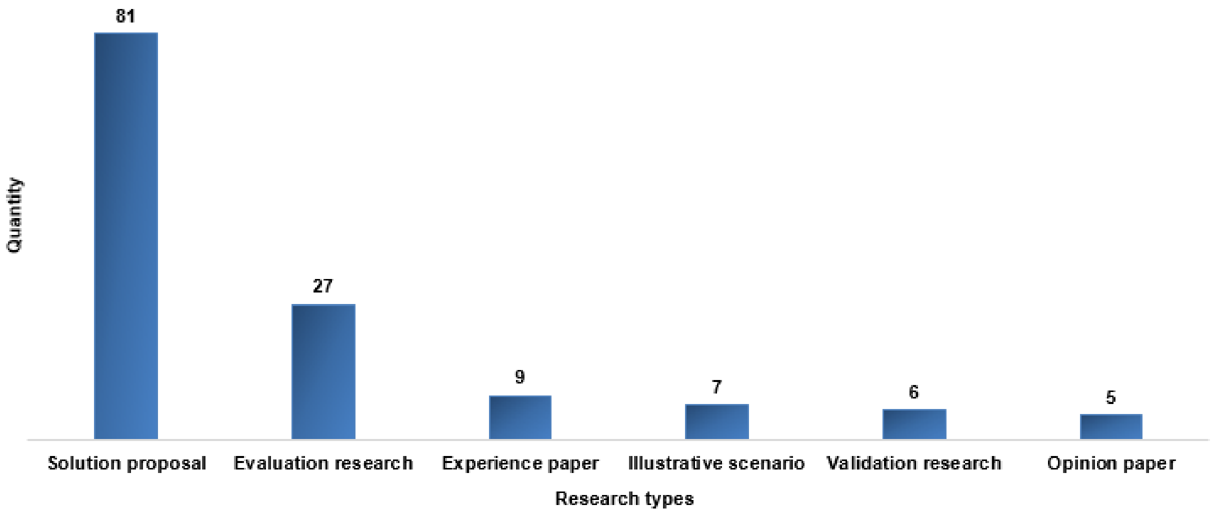

Figure 2-12 - Quantity of selected studies per research types.

On the Illustrative scenario papers, the aim was to verify those which propose a method applying to small examples, as the order allocation issue with suppliers under risk of business disruption investigated by Meena and Sarmah (2013). On the validation research, Okamuro (2001) developed a method to examine the risk-sharing in the Japanese automotive industry. In the last category, some papers provided their own opinion about supplier relationship – how it could be improved to reflect on the quality of products and increase customer satisfaction.

2.2.7.1 Approaches for SQM (RQ1)

The purpose of this research question (RQ1) is to seek and identify what the methods proposed for SQM are in the literature. From 135 papers selected in the SLR, we found 31 different methods (distributed in Figure 2-13) which correlate to the SQM.

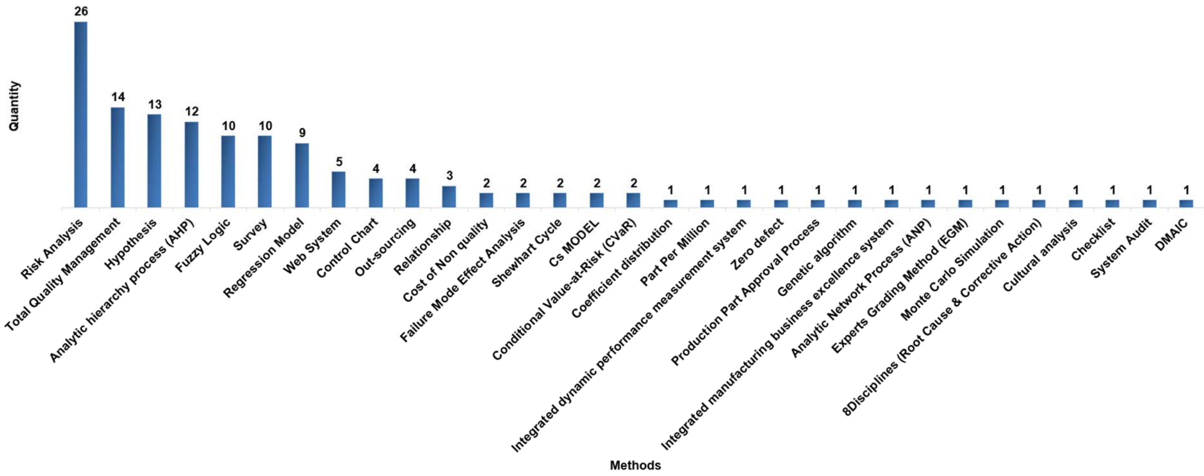

Figure 2-13 - Methods proposal for Supplier Quality Management.

The first approach is **Risk Analysis** with 19% of the articles. From the 26 papers, 7 are related to risk management, 6 are related to risk assessment, 5 are related to risk evaluation, 3 are related to risk measurement and 3 for mitigation and 2 for identification. Zhao and Cao (2015) investigated requirement, technical, performance, schedule and cost risks.

The second approach found in the SLR is **Total Quality Management** with 10% of articles. The TQM started to be famous and considered in the majority of industries in 1950, when “Quality” was finally considered as part of the business strategy and started to be recognized by the customers as an advantage, and those who did not apply the quality were ignored being under risk to close the doors (Marshal Junior et al., 2008). The TQM consists of the application of some quality tools in order to get better quality either from the production line (on the OEM) and supplier production line. It can be verified that some of these quality tools used in the TQM, were found in this SLR, as **Control Chart**, **Shewhart Cycle (PDCA), Failure Mode and Effect Analysis**, **Cost of Non-Quality**, **Out-sourcing**, **DMAIC**, **Zero defect**, **Part**

per million, **Production Parts Approval Process, 8D (8 Disciplines)**, **Checklist** and **System Audit**.

The third approach is the **hypothesis test** with 10% of articles. From the 13 articles, 5 applied ANOVA approach to test the hypothesis, 5 were applying T-Test and 3 were applying Chi-square. Phan and Matsui (2010) applied ANOVA and regression techniques to the database of the high performance manufacturing project to examine the similarities and differences across countries in Just-in-time implementation and the effect of Just-in-time production practices on operational performance.

The fourth approach is the **Analytic Hierarchy Process** (AHP) with 9% of articles, used as a multi-criteria decision-making approach in which factors are arranged in a hierarchic structure (Saaty, 1990), similar to **Analytic Network Process** (ANP). **Fuzzy Logic** was used on the supplier selection process or for purchase choices. There was a mix with fuzzy and risk analysis, as proposed by Xiao et al. (2012) in a supplier selection case considering some risk factors (as example the identification, assessment, analysis and treatment of areas with vulnerability and risk). The intention to use the fuzzy methods on the supplier selection is to make the buyer's life easier when a purchase order shall be sent to just one supplier in a supply chain with other competitors.

Shin et al. (2009) developed a probabilistic cost model to compare the alternative sourcing policies by quantifying suppliers aggregated performance on product quality and delivery. Overall, the results from the computational analysis are in favor of single sourcing, but further analysis shows that single sourcing may not be a panacea. Although potential quality cost savings under a single sourcing strategy appear greater than those of a dual or a multiple sourcing strategy, the single-sourcing policy needs that variations in the incoming quality level must be extremely marginal for all the single-source suppliers. Otherwise, dual sourcing would be better in terms of quality performance.

Followed by Fuzzy Logic, the **Survey** methodology represents 7% of articles found. In most of the articles, the Survey was not considered a tool for SQM but contributed to the quality verification or as a guideline on the surveys performed with people on the general industries.

The **Regression Model** is the seventh most adopted approach found in this SLR with 7% of articles. From the total of 9 articles, 7 articles were proposing a Linear

Regression Analysis, 1 proposing a Hierarchical regression analysis and 1 proposing Poisson–Gamma model. None of the articles found had the logistic regression method applied because they were not focused on supplier risk classification based on its quality performance during the series production.

Walter et al. (2003) and Lai et al. (2005) applied a linear regression analysis to demonstrate that a significant and good relationship between supplier, OEM and customer is necessary to improve the product quality. Okamuro (2001) verified through regression analysis that the carmakers in Japan are absorbing the business risk from the small suppliers once they have a greater risk-bearing capability due to their relatively higher degree of diversification and stronger financial power.

On this SLR, new methods for SQM were identified, as the Integrated Manufacturing Business Excellence System (**IMBES**) proposed by K.P et al. (2017), and the Integrated Dynamic Performance Measurement System (**IDPMS**) proposed by Chen and Cheng (2007). The **Experts Grading Method** (also called Delphi Method), has been proposed by Li et al. (2013) to reach the most accurate answer by decreasing the number of solutions each time the questionnaire is sent (to a group of experts).

Some other solutions have been proposed for the SQM as the investigation on how the (long-term) **Relationship** can contribute for a better quality integrating all the variables necessary for this on a **Web System** (portal), to keep all the transactions between customer and supplier registered for data analysis and actions taken.

Other methods proposed were the Control Chart suggested also by Sun et al. (2012), the Conditional Value-at-Risk (CVar) proposed by Talluri et al. (2010) and He et al. (2017), the Cs Model investigated by Wen et al. (2007), Poisson distribution (Quigley et al., 2018) and Monte-Carlo Simulation (Costantino, Pellegrino, 2010).

2.2.7.2 Approaches for Risk Assessment (RQ2)

The aim of the RQ2 available in

Table 2.3 – How the risk assessment has been taken into consideration in the literature - is to identify if the risk methodology has been proposed for SQM and in which conditions it could be applicable.

In the selected papers, It was found 26 (or 19% from the total) articles considering risk as part of the method for the SQM. From these articles, in 47% of them, the writers are proposing risk assessment or evaluation under supplier selection step, which means that risk need be found to allow the company to choose which supplier shall be selected for futures business.

Another 38% of articles are related to risk mitigation and risk management. The risk mitigation shall propose methods to verify in a period how suppliers are performing in terms of quality, cost, deliverables, etc. The risk management shall propose a method to deal with a risk not predicted (being this case the worst scenario). For the remaining articles, the writers are proposing how to identify and measure the risk in any scenario.

It is important to remember that the aim of the SLR is also to verify what the methods available are for SQM that could be applied in different companies. However, it’s necessary to consider that in terms of business, the risk mitigation in the supplier selection phase could be selected as well, but not for this work (that considers the problem already happened).

Chapter 3

METHODOLOGY

The RQ1 and RQ2 were responded in the SLR performed and explained in section 2.2. The proposal is to apply a statistical method to obtain the risk index calculation for a set of suppliers from some observed factors in the Supplier Quality Management area. So, the Logistic regression is the appropriate method for this scenario considering that estimates a risk ranking from a series of independents or exploratory variables.

However, before the calculation development, it's necessary to define first which variables (factors) should be considered. After this, the statistical analysis will be executed and the results will be analyzed.

3.1 Method

Hosmer and Lemeshow (2000) state that the strength of a modeling technique lies in its ability to model many variables, some of which may be on different measurement scales – this is referred to as the multivariable case. Considering a collection of p independent variables denoted by the vector $\mathrm{X}' = (X_1, X_2, \dots, Xp)$ and letting the conditional probability that the outcome is present to be denoted by $\mathrm{P}(\mathrm{Y} = 1|X) = \pi(X)$, the logit (or logistic model) of the multiple logistic regression model is given by the equation:

$$g(x) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_p x_p$$

In which case the logistic regression model is:

$$\pi(X) = \frac{e^{g(X)}}{1 + e^{g(x)}}$$

To adjust a logistic regression model for a dataset, is necessary to estimate the (coefficients) β's of unknown parameters. The Regression coefficients are estimated using the maximum likelihood method and, subsequently, a significance test is performed (Mendonça, 2008).

Hosmer and Lemeshow (2000) assert that to test the significance of the coefficient of a variable in any model relates to the following question: "Does the model that includes the independent variable in question tell us more about the outcome (or response) variable than a model that does not include that variable?". The answer comes when it is compared the observed values of the response variable to those predicted by each of two models – the first with and second without the variable in question.

For the dichotomous independent variable, it is important to understand the *odds ratio,* denoted OR, that is defined as the ratio of the odds for $x = 1$ to the *odds* for $x = 0$ and is given by the equation:

$$OR = \frac{\pi(1)/[1 - \pi(1)]}{\pi(0)/[1 - \pi(0)]}$$

where the *odds* of the outcome being present among individuals with X= 1 is defined as $\pi(1)/[1 - \pi(1)]$ and for X $= 0$ is defined as $\pi(0)/[1 - \pi(0)]$. The *odds ratio* is a measure of association that has found wide use as it approximates how much more likely (or unlikely) it is for the outcome to be present among those with $X = 1$ than among those with X= 0 (Hosmer and Lemeshow, 2000).

After estimating and interpreting the coefficients in a logistic regression model, it necessary to verify if each variable has a significant correlation with the response variable.

The traditional approach to statistical model building involves seeking the most parsimonious model – best fitting and with a minimum quantity necessary of factors. The rationale for minimizing the number of variables in the model is that the resultant model is more likely to be numerically stable and is more easily generalized. The more variables included in a model, the greater the estimated standard errors become, and the more dependent the model becomes on the observed data.

There are three variable selection methods: stepwise, forward addition and backward elimination. The stepwise selection of variables technique provides a fast and effective means to screen a large number of variables and to fit a number of logistic regression equations simultaneously. Any stepwise procedure for the selection or deletion of variables from a model is based on criteria as Wald test, that checks for the significance of the logistic coefficient. Its interpretation is like F or t values used for the significance testing of regression coefficients, as explained by Hair Jr et al. (2014).

In the forward addition approach, it is considered the variable with the higher correlation coefficient observed with the response variable and each interaction with other variables can be added. If any variable is not added, the process stops and defines the final model.

The backward elimination approach consists working backward from the largest starting model to a smaller final treating variables of different orders at different steps, which means to consider simplifying the model by eliminating unnecessary interaction and/or confounding terms, starting from the highest-order terms to the next highest-orders terms and so on (Kleinbaum, Klein, 2002).

3.1.1 Data Source

In the dependent variable selection, it was defined in this work the supplier quality performance status, considering good or bad suppliers based on their limit of rejections that are defined by the aerospace company in a yearly basis.

As the dependent variable shall be binary, it was considered the following scenarios:

- Supplier performance less or equal than the limit = 0.
- Supplier performance above the limit = 1.

A set of suppliers was defined with 201 suppliers, which deliveries parts to the company and have their quality performance monitored on a monthly basis. The timeframe considered was 11 months (October 2018 – August 2019) due to limitations in the available data by the aerospace company. However, the database considered was from October 2018 to June 2019, with the July 2019 data being used to verify the suppliers limit (response variable) and month of August 2019 was used to analyze the regression analysis results with the risk calculated by the aerospace company.

Considering the information provided in sub-section 2.1.3.4, a set of 14 variables were defined to be used in the logistic regression calculation (available in Table 3.1).

Table 3.1 – Variables applied in the logistic regression.

Description	Variable name	Comments
1. Quality System	QS_June19	It was considered the status of each supplier in June. If supplier had Certification A, B or did not have any one.
2. Quality System	QS_total	It was considered if supplier had or not a certification in the last 9 months.
3. Quantity of non-conformances	Rej_total	It was considered the sum of rejections for each supplier in the last 9 months divided in 4 quarters.
4. Special process	SP_June19	It was considered if supplier had in June, an international or internal certification or did not have any one.
5. Special process	SP_9M	It was considered if supplier had or not a certification in the last 9 months.
6. Contractual requirement	CR_June19	It was considered if supplier had the latest contract revision signed.
7. Contractual requirement	CR_9M	It was considered if supplier had the latest contract revision signed in the last 9 months.
8. Changes	Change_June19	It was considered if supplier have a change registered or not in June.
9. Changes	Change_9M	It was considered if supplier had or not a change mapped.
10. Product criticality	Critical_June19	It was considered the supplier part criticality in June.
11. Quality Escape	QE_total	It was considered if supplier had or not an escape in the last 9 month.
12. Production material shortage	Material_total	It was considered if supplier had or not a material shortage in the last 9 months.
13. Corrective action	Action_total	It was considered if supplier had or not an action in the last 9 months.
14. Variable response	Y	Provides information of supplier's status in July-2019 considering the level of rejections based on their limits: 0 = Good supplier. 1 = Bad supplier.

The independent variables QS_June19, SP_June19, CR_June19, Change_June19 and Critical_June19 aims to verify the status of each supplier in that specific month. However, besides the status in that specific month, it was verified the importance to check the supplier performance in a long period of time and not in a specific month. Based on this, the variables QS_total, SP_9M, CR_9M and Change_9M were created.

The variable response “Y” considered the supplier performance in the month of July-2019. If the number of rejections were below the supplier limit, It was considered as a good supplier (=0). It the number of rejections was above the limit, It was considered as a bad supplier (=1).

The variable Rej_total was divided in 4 quarters in order to reduce the outlier that could impact the results (due to the data dispersion in the non-conformances quantity.

The analysis was done using the statistical software SSPS. The level of significance considered was 5% and the variable selection method used was backward.

Chapter 4

RESULTS AND DISCUSSION

A backward stepwise analysis was conducted, thus eliminating the non-significant variables one at the time and retaining only the statistically significant variables.

The logistic regression model was adjusted with all the variables informed in Table 3.1 considering the backward selection method. The final model adjusted is presented in Table 4.1.

Table 4.1 – Significant variables results.

	β	S.E. β	Wald	df	p-value	OR(e^{β})	IC95%OR
Rej_total			38,276	3	0,00		
Rej_total (1 part)	1,22	0,72	2,86	1	0,09	3,39	0,82;13,96
Rej_total (2 to 9 parts)	2,38	0,67	12,55	1	0,00	10,81	2,89;40,35
Rej_total (>9 parts)	3,61	0,68	28,51	1	0,00	37,04	9,83;139,46
Change_June19(Yes)	1,94	0,71	7,38	1	0,00	6,97	1,71;28,27
Constant	-4,83	0,93	27,07	1	0,00	0,00	

β: parameter; S.E.: standard error; df: degrees of freedom; OR: odds ratio; IC95%OR: 95% confidence interval for odds ratio.

The Rej_total is the reference due to the lack of rejections. As higher the number of parts rejected, higher is the chance of supplier being considered as bad when compared with the Rej_total. The same for Change_June19 (Yes), which means that the supplier with a change mapped in June19, had 6,97 more chances to fail when compared to the supplier which did not have change mapped.

The hit rate or the percentage correctly classified for the final model was calculated and resulted in 78,6% (**Erro! Fonte de referência não encontrada.**).

Table 4.2 – Percentage of classification.

Observed		Predicted		
		Y		Percentage Correct
		0	1	
Y	0	130	14	90,3
	1	29	28	49,1
Overall Percentage				78,6

A correlation analysis between the logistic regression score with the risk calculated in August 2019 (by the aerospace company) was done to verify if both risks are converging to the same direction. The analysis was performed using the Spearman method, and resulted in r=0.41; p-value<0.001, which indicated (in Figure 4-1) that there is a statistically significant correlation.

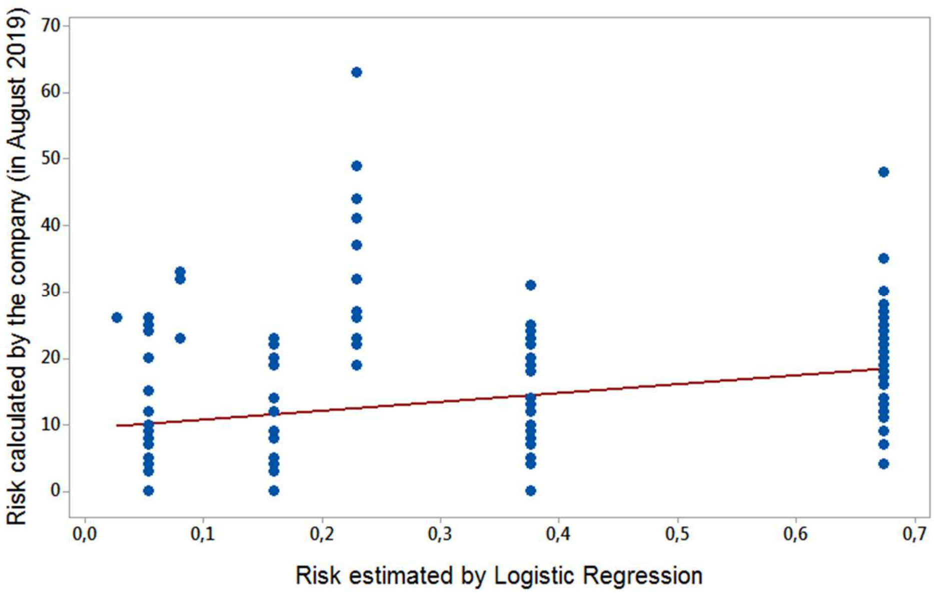

Figure 4-1 – Correlation between risk estimated by regression and the one calculated by company.

The objective of this work was to get as a result of a ranking of suppliers through a regression logistic calculated and then make analyzes result with the aerospace company risk generated in August 2019. However, the logistic regression technique predicts a probability value between 0 and 1. This predicted probability is based on the value(s) of the independent variable(s) and the estimated coefficients (Hair Jr et al., 2014).

Therefore, the final logistic regression model resulted in 7 groups of suppliers with their risks (as highest is the predict, highest is the risk), available in **Erro! Fonte de referência não encontrada.**.

Table 4.3 – Group of suppliers per predict.

Predict	Quantity of suppliers	Explanation
0,672	42	Rejections greater than 9 with supplier change.
0,375	42	Rejections between 3 and 9 with supplier change.
0,227	12	Rejections greater than 9.
0,158	44	1 or 2 Rejections with supplier change.
0,079	3	Rejections between 3 and 9.
0,052	57	No rejections with supplier change.
0,026	1	1 or 2 Rejections.
Total	201	

In the final list of suppliers per group of risk (available in Appendix 2), It was added the ranking from the risk calculated by the aerospace company in August of 2019 (the risk value was replaced by an ordinary number to facilitate the validation).

It was analyzed a sample of suppliers in the group with the highest risk (0,67). The intention was to verify why some suppliers were classified with a high risk in the logistic regression but were classified as low risk by the aerospace company in the risk calculation in August 2019. The result is available in **Erro! Fonte de referência não encontrada.**.

The analysis was done taking into consideration the two significant variables defined by the final logistic regression model (**Erro! Fonte de referência não encontrada.**), the quantity of rejections that supplier had in the last 9 months, the limit of failures in 9 months and also the risk results calculated by the aerospace company in August 2019.

Table 4.4 – Analysis performed on suppliers classified with the highest score by logistic regression.

Supplier Name	August 2019 Risk	Predict	Number of Rejections in the L9M	Limit of total rejections in 9 months	Changes in June19
Supplier 37	43	0,67	11	0	0
Supplier 65	45	0,67	34	9	0
Supplier 42	53	0,67	23	9	0
Supplier 74	57	0,67	30	9	0
Supplier 138	63	0,67	34	9	0
Supplier 140	65	0,67	41	9	0
Supplier 29	71	0,67	198	135	0
Supplier 55	75	0,67	21	0	0
Supplier 137	76	0,67	12	0	0
Supplier 168	81	0,67	57	27	0
Supplier 49	84	0,67	19	9	0
Supplier 17	86	0,67	12	9	0
Supplier 46	89	0,67	25	18	0
Supplier 30	92	0,67	16	0	0
Supplier 181	94	0,67	21	18	0
Supplier 158	95	0,67	35	27	0
Supplier 174	103	0,67	11	9	0
Supplier 149	109	0,67	43	9	0
Supplier 41	118	0,67	10	9	0
Supplier 106	122	0,67	23	18	0
Supplier 155	127	0,67	14	0	0
Supplier 115	168	0,67	21	9	0
Supplier 128	171	0,67	45	36	0

Supplier 130	201	0,67	47	0	0

L9M = Last 9 months.

The suppliers in the **Erro! Fonte de referência não encontrada.** had the number of rejections in the last 9 months above than the limit allowed, which was considered as a dependent variable in the logistic regression model. Thus, It can be concluded that the final model accepted selecting this suppliers.

In this work, It was considered the sum of rejections that each supplier had in the last 9 months (to avoid a situation where the supplier could present a good performance in the short period of time but had a bad performance before on Its history) and also the supplier limit. However, the aerospace company apply a different concept in the risk analysis.

Considering the supplier history of failures, It was analyzed the supplier 149, which was classified as high risk by the logistic regression model. This supplier had 43 rejections between October 2018 and August 2019, however the limit allowed was 9 removals in the total. Excepting in July 2019, this supplier has been presented rejections in a monthly basis according to Figure 4-2.

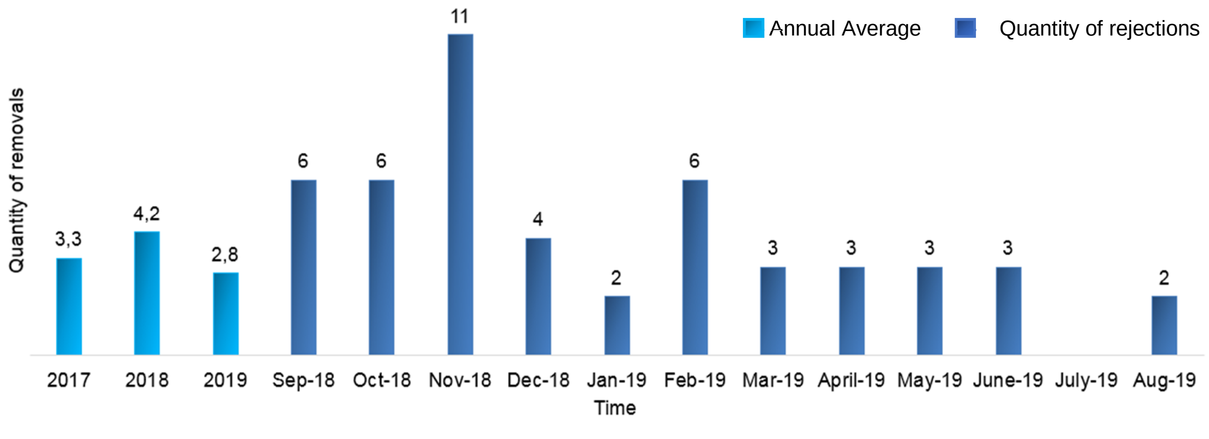

Figure 4-2 – Number of rejections for Supplier 149.

With a difference approach in relation to the timeline, the risk calculated by the aerospace company has not been classified this supplier as a high risk. The **Erro! Fonte de referência não encontrada.** shows the supplier position in the previous risk calculated. Except in May 2019, supplier was ranked after position 100, from a total of 201 suppliers.

Table 4.5 – Supplier 149 ranking classified by aerospace company method.

Month/2019	May	June	July	August
Position	42	102	122	109

Another situation that explains the difference between both methods happens when the supplier's performance is seasonal. Figure 4-3 shows a scenario where the supplier 181 presents a number of failures in a period time – between October 2018 and December 2018 and May 2019 and August. The risk calculation done by the aerospace company may fail to classify this supplier as a high risk, as according to **Erro! Fonte de referência não encontrada.**.

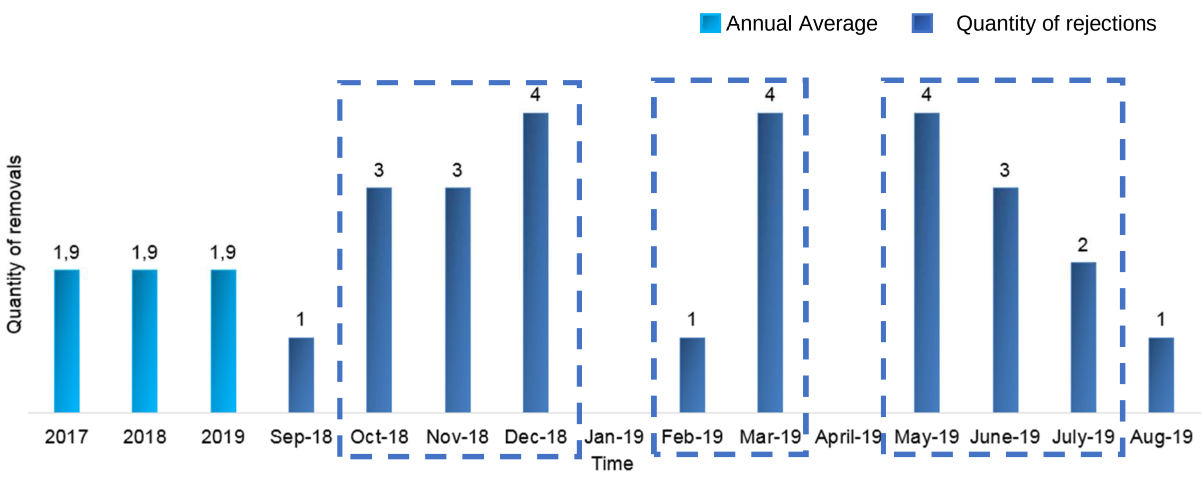

Figure 4-3 – Number of rejections for Supplier 181.

Table 4.6 – Supplier 181 ranking classified by aerospace company method.

Month/2019	May	June	July	August
Position	131	103	83	110

It was verified in table available in Appendix 2 that some suppliers considered in the first positions of aerospace company ranking calculated in August 2019 were not in the first group of risk resulted in the logistic regression method applied.

The first supplier from the August 2019 risk ranking (Appendix 2) is the supplier 150 that was classified in the third group of risk defined by logistic regression model. After an analysis, it was identified that this supplier had 213 rejections in the last 9 months and a change was mapped in the variable Change_June19. Based on this, the supplier should be classified by the logistic regression method in the first group of risks.

As the method has an error rate of 21%, this supplier was wrongly classified. In this case, this supplier should be manually classified as high risk. The same action should be done for supplier 36, which was classified in the third position in the August 2019 risk but is part of the third group of risk defined by the logistic regression.

The supplier classified in position 4 in the August risk, is part of the third group of risk defined by the logistic regression. In this case, it was identified that the supplier had 66 removals in the last 9 months, however, the limit for rejections is 72, which means that the supplier can be considered with a low risk once the quantity of removals is inside of its limit. A revision on the limit could be applied.

Chapter 5

CONCLUSION

This section presents the conclusion of this work with its contribution. The application of logistic regression is common to be used in the supplier selection but not for the supplier quality management. There is a gap in the literature about this application in the SQM. Future works and restrictions on this work are also proposed in this chapter.

5.1 Contributions

The current work presented the great importance of the multivariate data analysis as an aid to decision making.

The work proposal aimed to calculate the risk of a worldwide and complex supply chain from an aerospace company based on the quality performance analysis to rank and select them for improving the competitiveness of the whole supply system. Two research questions were created to help on the main proposal, being them answered through a performed systematic literature review.

The purpose of the first question was to seek and identify what were the main methods proposed for the SQM available in the literature. From 31 different methods found, the most used method was Risk Analysis, with 19% of the articles. From the 26 papers, seven are related to risk management; six to risk assessment, five are related to risk evaluation, three are related to risk measurement, and two for mitigation and identification.

The Regression Model was some of the most adopted approach found in this SLR with 7% of articles. From the total of 9 articles, 7 articles were proposing a Linear Regression Analysis, 1 proposing a Hierarchical regression analysis and 1 proposing Poisson–Gamma model. None of the articles found had the logistic regression method applied because they were not focused on supplier risk classification based on its quality performance during the series production

As the main purpose of this work was to calculate the risk from a set of suppliers managed by the aerospace company applying a statistical technique, it was chosen the logistic regression model. Sluis and De Giovanni (2016) used this model to investigate through an empirical study the key drivers for a supplier selection and identified that the risk on supplier selection is based on the supplier performance level (quantity of parts rejected).

For this work, it was considered the supplier rejections limits as the critical point to define if the supplier could be considered good or bad. From the set of variables considered in the logistic regression calculation, the model identified two main significative variables: Rej_total (number of rejections) and Change_June19 (supplier process change).

The application of the logistic regression method resulted in 7 groups of suppliers with levels of risk. Some of the suppliers from the first group were analyzed and based on the results, a final model provided indications on suppliers that are facing a bad performance in the aerospace company and need to have an action plan to improve their performance. The verification of supplier performance in a long time contributes to identifying some cases that even the supplier does not have a high number of rejections, but has a constant rejections.

The results of modeling made by applying the logistic regression in this work were considered good, with a hit rate of 78,6% of the cases. For the suppliers wrongly classified, it is necessary an investigation to identify errors and address improvements in the database or in the calculation. The hit rate of risk calculated by the aerospace company was not verified, however, in practice, some suppliers may need to be manually classified by the SQM team when the risk was not high. The same investigation shall be performed.

5.2 Innovation

The application of logistic regression has existed for a long time but has not being applied in the aerospace supplier quality management. The use of this method in a worldwide supply chain from an aerospace company may contribute to having better supply management and an improvement in supplier performance based on the best fitting on the risk analysis.

5.3 Future work

For future works, the suggestions are:

- To consider other dependent variables in the logistic regression model, as quality system, supplier production change, or other. The purpose is to verify if the supplier limit is the best approach to determine whether the supplier is good or not from a quality standpoint. This definition shall be in alignment with a high-level management team and quality directives.
- To consider other methods for the supplier management as Cluster analysis or artificial intelligence models, in order to raise the hit rate.
- To develop a system that provides a list with critical suppliers based on statistical methods and that allows the management team to take a fast and assertive approach for each supplier.

5.4 Restriction

The restriction verified in this work was the limitation of data available by the aerospace company in terms of time and sample size. As bigger is the sample base, the model would capture a better supplier performance history. According to Hair Jr et al. (2014), small samples may have sampling error and very large sample sizes increase the statistical result and decrease the rate of error.

It was verified and analyzed the supplier performance instead of the part performance. A verification in the part level would provide the exact information on when and how many parts were received and rejected. This would help in a final model error reduction.

Due to confidentiality and/or proprietary information, some of the information was hidden.

APPENDIX

Appendix 1 – Papers resulted from the systematic literature review.

#	Title	Authors	Database
1	Cost and Benefit Analysis of Supplier Risk Mitigation in an Aerospace Supply Chain	Abroon Qazi, John Quigley, Alex Dickson, Barbara Gaudenzi and Şule Önsel Ekici	IEEE
2	DEVELOPMENT OF SUPPLIER QUALITY PERFORMANCES IN A SEMICONDUCTOR COMPANY FOR ISTMET2015	Norzima Zulkifli, Faieza bt. Abd. Aziz and Sangeethavani Sivalingam	IEEE
3	Supplier Quality Improvement-The Key to Long-Term Quality Relationships	JoEllen Walker, Samuel E. Hon	IEEE
4	A Study of Supplier Selection and Quality Strategy Based on Quality Costs Theory	WANG Qing-e, GUO Xiao-min	IEEE
5	A Study on Quality Management for Aerospace Product with Multilevel Suppliers	Haoli CHANG, Haicheng YANG, Haibin LIU, Junjie HOU	IEEE
6	A Supplier Performance Evaluation Solution for Proactive Supplier Quality Management	Sai Zeng, Mitchell A. Cohen, Benjamin J. Steele, Jakka Sairamesh	IEEE
7	CHEMICAL SUPPLIER QUALITY MANAGEMENT: THE CHANGES AND CHALLENGES	Jini 0 'Brien, Terry Leslie	IEEE
8	The Supplier' s Attitude to Quality and Reliability	SAUL, G. D.	IEEE
9	Customer and Suppliers cooperate for quality improvement	Kreager, Richard M	IEEE
10	Estimating supplier's hidden quality costs with Taguchi quality loss function and Topsis method	Jenoui, Kaoutar Abouabdellah, Abdellah	IEEE
11	Learning from auto makers and path dependence: Conflicting modes to promote suppliers' innovation quality	Lin, Yan Chen, Yan	IEEE
12	An effective approach for utilities and suppliers to assess the quality of new products before purchase	Hamblin, M W Wilczynski, P P	IEEE
13	Suppliers and quality - Parts per million	C. J. Allington	IEEE
14	A Quality Framework " e-Supplier Platform " to improve material quality and feedback for process control	Chen, Jia-huey Leu, Chien-hui Chang, Wei-fu Hsu, Tun-Kai.	IEEE

15	A Supplier Quality Control Model for Large Passenger Aircraft Under the Asymmetric Information	Chuanmin Mi, Jing Ma, Yuan Qiang, Zhenzhen Ma, Peng Peng	IEEE
16	Only world class suppliers need apply	R. Ayliffe, N. Irwin	IEEE
17	Partnering relationships with suppliers result in improved cost, quality and delivery performance	Patti Wasmund	IEEE
18	Quality Dimensions Relevant to a First Tier Automotive Supplier: Case Study at an Automotive Seat Cover Supplier	Kem Ramdass	IEEE
19	An empirical analysis of supplier risk	Zhong, Sheng Feng, Dan Zeng, Meng Qi	IEEE
20	Quality Investment And Cost-Sharing In The Manufacturer-Supplier Cooperative Development For Complex Products	Li, Yaping Liu, Sifeng Fang, Zhigeng	IEEE
21	The SEMATECH SSQA for Supplier - User Partnering, Quality Assessment and Continuous Improvement	Schuler, John	IEEE
22	Two Stage Procurement Processes With Competitive Suppliers and Uncertain Supplier Quality	Jin, Yue Ryan, Jennifer K. Yund, Walter	IEEE
23	Supplier Evaluation with Quality-Based Fuzzy Data	Chiang, Ching Y. Shu, Ming Hung	IEEE
24	Modeling Supplier Selection and the Use of Individual Advantage Characteristics for High-Quality Supply Chain Design	Zhu, Z. Zhu, Y. L.	IEEE
25	A control chart design for supplier in view of quality, due time and cost	Sun, J. Matsui, M.	IEEE
26	Out-sourcing rediscovered: Purchasing parts and even complete vehicles from independent suppliers can keep costs down and quality up	Michael S. Flynn	IEEE
27	An approach to supplier Quality improvement	Trent, J. E.	IEEE
28	The CAPD Model of x Chart with Tardiness Penalty for Improving Supplier Quality	Sun, J Tsubaki, M Matsui, M	IEEE
29	Improving software delivery quality via the customer-supplier team	William M. Pratt	IEEE
30	Research on Control Charts and Process Capability Analysis in Supplier Quality Management	Zhang Qinghua, Wang Zhuan, Cheng Guoquan, Zhang Lili, Gao Jing	IEEE
31	ESTABLISHING A SYSTEM TO IMPROVE THE QUALITY OF MATERIAL FROM THE SUPPLIER	Bothwell, Rod	IEEE
32	Study on Supplier's Quality Supplying Competence Index in the Case of Multi-quality Characteristics without Excursion	Wen, Decheng Li, Kaipeng Wang, Gaoshan	IEEE

33	Study on Supplier’s Quality Supplying Competence Index in the Case of Multi-quality Characteristics with Excursion	Kaipeng Li, Shujing Zhang	IEEE
34	Clustering of Suppliers' Quality-based Strategies in Italy: The Case of the Automotive, Telecommunication, and Electromechanical Industries	Lo Storto, Corrado	IEEE
35	Monitoring Supplier Quality at PPM Levels	Fabia, Jojo M.	IEEE
36	The Partnership between OEM Supplier and System Manufacturer - An Example for Total Quality Management	Neswadba, Horst G	IEEE
37	City Distribution Service Quality: A Factor Impacting on Supplier-customer Relationship and Customer Satisfaction	Cui, Li Zhang, Hao He, Mingke Wang, Jingyuan	IEEE
38	Risk management processes in supplier networks	Jukka Hallikasa, Iris Karvonenb, Urho Pulkkinenb, Veli-Matti Virolainenc, Markku Tuominen	Science Direct
39	Risk-based classification of supplier relationships	Jukka Hallikasa, Kaisu Puumalainenb, Toni Vesterinenb, Veli-Matti Virolainenb	Science Direct
40	Global supplier development considering risk factors using fuzzy extended AHP-based approach	Felix T.S. Chan, Niraj Kumar	Science Direct
41	A modified failure mode and effects analysis method for supplier selection problems in the supply chain risk environment: A case study	Ping-Shun Chen ⇑, Ming-Tsung Wu	Science Direct
42	A deterministic, multi-item inventory model with supplier selection and imperfect quality	Jafar Rezaei, Mansoor Davoodi	Science Direct
43	A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks	Amy H.I. Lee	Science Direct
44	A Game Theoretic Model to Manufacturing Planning with Single Manufacturer and Multiple Suppliers with Asymmetric Quality Information	Sisi Yina, Tatsushi Nishia, Guoqing Zhang	Science Direct
45	A note on ‘‘Quality investment and inspection policy in a supplier-manufacturer supply chain’’	Gerhard Aust, Ina Bräuer, Udo Buscher	Science Direct
46	A proactive approach to supply chain risk management: Shifting orders among suppliers to mitigate the supply side risks	Kırılmaz, Oguzhan, Erol, Serpil	Science Direct
47	A Review and Synthesis of Research on Supplier Concentration, Quality and Fee Structure in Non-U.S. Markets for Auditor Services	Walker, Kenton B., Johnson, Eric N.	Science Direct

48	A supplier selection model with fuzzy risk analysis using the balanced solution technique with a soft set	Patra, Kartik Mondal, Shyamal Kumar	Science Direct
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58	Capacity investment in supply chain with risk averse supplier under risk diversification contract	He, Juan; Ma, Chao; Pan, Kai	Science Direct
59	Supplier Teaming and Procurement Quality Assurance	Joseph Berk, Susan Berk	Science Direct
60	Choosing between single and multiple sourcing based on supplier default risk: A real options approach	Costantino, Nicola; Pellegrino, Roberta	Science Direct
61	Compound mechanism design of supplier selection based on multi-attribute auction and risk management of supply chain	Rao, Congjun Xiao, Xinping Goh, Mark; Zheng, Junjun; Wen, Jianghui; Rao, Congjun; Xiao, Xinping	Science Direct
62	Control mechanisms across a buyer–supplier relationship quality matrix	Liu, Yi; Li, Yuan; Zhang, Leinan	Science Direct

63	Customer pressure, customer–manufacturer–supplier relationships, and quality control performance	Ueki, Yasushi	Science Direct
64	Factors affecting supplier quality performance	Forker, L. B.	Science Direct
65	Functions of industrial supplier relationships and their impact on relationship quality	Walter, Achim Müller, Thilo A.; Helfert, Gabriele; Ritter, Thomas	Science Direct
66	Fuzzy multi-objective programming for supplier selection and risk modeling: A possibility approach	Wu, Desheng Dash Zhang, Yidong; Wu, Dexiang; Olson, David L.	Science Direct
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75	Multi-attribute procurement auctions with risk averse suppliers	Liu, Shulin; Li, Jun; Liu, De	Science Direct
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83	Quality-based supplier selection and evaluation using fuzzy data	Ming-Hung Shua, Hsien-Chung Wu	Science Direct
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85	Reducing the total cost of supply through risk-efficiency-based supplier selection in the EPC industry	Guido J.L. Micheli, Enrico Cagno, Augusto Di Giulio	Science Direct
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87	Supplier selection and order allocation under disruption risk	Dupont, L. Ghorbel, A. Hamdi, F. Masmoudi, F.	Science Direct
88	Risk management on joint product development with power asymmetry between supplier and manufacturer	Yanlu Zhao, Hui Cao	Science Direct
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135	The Utilization of Quality KPIs in the Pharmaceutical Industry	Torkko, Marianne Katajavuori, Nina Linna, Anu Juppo, Anne Mari	Springer Link

Appendix 2 - Supplier's risk per Logistic regression result.

ID	Supplier Name	Risk calculated by the company (in August 2019)	Risk estimated by Logistic Regression
1	Supplier 151	3	0,67296
2	Supplier 113	6	0,67296
3	Supplier 92	8	0,67296
4	Supplier 75	11	0,67296
5	Supplier 164	13	0,67296
6	Supplier 186	14	0,67296
7	Supplier 86	16	0,67296
8	Supplier 38	17	0,67296
9	Supplier 35	20	0,67296
10	Supplier 179	21	0,67296
11	Supplier 34	22	0,67296
12	Supplier 82	26	0,67296
13	Supplier 118	28	0,67296
14	Supplier 112	30	0,67296
15	Supplier 18	32	0,67296
16	Supplier 183	36	0,67296
17	Supplier 26	41	0,67296
18	Supplier 97	42	0,67296
19	Supplier 37	43	0,67296
20	Supplier 65	45	0,67296
21	Supplier 42	53	0,67296
22	Supplier 74	56	0,67296
23	Supplier 138	66	0,67296
24	Supplier 140	67	0,67296
25	Supplier 29	71	0,67296
26	Supplier 55	75	0,67296
27	Supplier 137	76	0,67296
28	Supplier 168	81	0,67296
29	Supplier 17	84	0,67296
30	Supplier 49	85	0,67296
31	Supplier 46	89	0,67296
32	Supplier 30	92	0,67296
33	Supplier 181	94	0,67296
34	Supplier 158	95	0,67296
35	Supplier 174	103	0,67296
36	Supplier 41	108	0,67296
37	Supplier 106	117	0,67296
38	Supplier 149	121	0,67296
39	Supplier 155	122	0,67296
40	Supplier 115	168	0,67296
41	Supplier 128	169	0,67296
42	Supplier 130	194	0,67296

43	Supplier 61	15	0,37528
44	Supplier 184	19	0,37528
45	Supplier 40	23	0,37528
46	Supplier 19	34	0,37528
47	Supplier 62	37	0,37528
48	Supplier 198	39	0,37528
49	Supplier 2	40	0,37528
50	Supplier 76	52	0,37528
51	Supplier 96	60	0,37528
52	Supplier 21	61	0,37528
53	Supplier 53	63	0,37528
54	Supplier 98	65	0,37528
55	Supplier 107	69	0,37528
56	Supplier 194	72	0,37528
57	Supplier 108	74	0,37528
58	Supplier 10	82	0,37528
59	Supplier 16	83	0,37528
60	Supplier 79	86	0,37528
61	Supplier 91	87	0,37528
62	Supplier 163	88	0,37528
63	Supplier 119	91	0,37528
64	Supplier 60	97	0,37528
65	Supplier 124	98	0,37528
66	Supplier 193	100	0,37528
67	Supplier 80	104	0,37528
68	Supplier 52	110	0,37528
69	Supplier 68	112	0,37528
70	Supplier 103	115	0,37528
71	Supplier 116	118	0,37528
72	Supplier 185	125	0,37528
73	Supplier 192	126	0,37528
74	Supplier 1	128	0,37528
75	Supplier 88	141	0,37528
76	Supplier 161	156	0,37528
77	Supplier 178	161	0,37528
78	Supplier 6	165	0,37528
79	Supplier 47	166	0,37528
80	Supplier 134	170	0,37528
81	Supplier 154	173	0,37528
82	Supplier 196	174	0,37528
83	Supplier 102	190	0,37528
84	Supplier 139	195	0,37528
85	Supplier 150	1	0,22797
86	Supplier 36	2	0,22797
87	Supplier 67	4	0,22797
88	Supplier 44	5	0,22797

89	Supplier 166	7	0,22797
90	Supplier 135	9	0,22797
91	Supplier 131	12	0,22797
92	Supplier 100	27	0,22797
93	Supplier 133	29	0,22797
94	Supplier 101	38	0,22797
95	Supplier 11	54	0,22797
96	Supplier 109	57	0,22797
97	Supplier 121	10	0,15849
98	Supplier 111	25	0,15849
99	Supplier 20	47	0,15849
100	Supplier 32	55	0,15849
101	Supplier 33	62	0,15849
102	Supplier 143	68	0,15849
103	Supplier 23	70	0,15849
104	Supplier 50	80	0,15849
105	Supplier 110	90	0,15849
106	Supplier 39	93	0,15849
107	Supplier 187	99	0,15849
108	Supplier 123	101	0,15849
109	Supplier 54	102	0,15849
110	Supplier 189	105	0,15849
111	Supplier 7	107	0,15849
112	Supplier 48	109	0,15849
113	Supplier 83	113	0,15849
114	Supplier 85	114	0,15849
115	Supplier 105	116	0,15849
116	Supplier 126	119	0,15849
117	Supplier 147	120	0,15849
118	Supplier 160	124	0,15849
119	Supplier 176	134	0,15849
120	Supplier 77	135	0,15849
121	Supplier 27	137	0,15849
122	Supplier 14	140	0,15849
123	Supplier 4	142	0,15849
124	Supplier 13	143	0,15849
125	Supplier 15	144	0,15849
126	Supplier 22	145	0,15849
127	Supplier 72	148	0,15849
128	Supplier 136	153	0,15849
129	Supplier 146	154	0,15849
130	Supplier 148	155	0,15849
131	Supplier 165	157	0,15849
132	Supplier 167	158	0,15849
133	Supplier 170	159	0,15849
134	Supplier 177	160	0,15849

135	Supplier 180	162	0,15849
136	Supplier 191	163	0,15849
137	Supplier 145	177	0,15849
138	Supplier 25	178	0,15849
139	Supplier 63	188	0,15849
140	Supplier 152	197	0,15849
141	Supplier 172	18	0,07936
142	Supplier 122	24	0,07936
143	Supplier 173	59	0,07936
144	Supplier 171	31	0,05263
145	Supplier 175	33	0,05263
146	Supplier 190	35	0,05263
147	Supplier 5	46	0,05263
148	Supplier 24	48	0,05263
149	Supplier 81	49	0,05263
150	Supplier 125	50	0,05263
151	Supplier 129	51	0,05263
152	Supplier 132	58	0,05263
153	Supplier 90	64	0,05263
154	Supplier 95	73	0,05263
155	Supplier 57	77	0,05263
156	Supplier 70	78	0,05263
157	Supplier 162	79	0,05263
158	Supplier 94	96	0,05263
159	Supplier 195	106	0,05263
160	Supplier 58	111	0,05263
161	Supplier 159	123	0,05263
162	Supplier 200	127	0,05263
163	Supplier 8	129	0,05263
164	Supplier 9	130	0,05263
165	Supplier 12	131	0,05263
166	Supplier 120	132	0,05263
167	Supplier 156	133	0,05263
168	Supplier 3	136	0,05263
169	Supplier 59	138	0,05263
170	Supplier 153	139	0,05263
171	Supplier 66	146	0,05263
172	Supplier 71	147	0,05263
173	Supplier 73	149	0,05263
174	Supplier 87	150	0,05263
175	Supplier 93	151	0,05263
176	Supplier 114	152	0,05263
177	Supplier 197	164	0,05263
178	Supplier 64	167	0,05263
179	Supplier 141	171	0,05263
180	Supplier 144	172	0,05263

181	Supplier 28	175	0,05263
182	Supplier 56	176	0,05263
183	Supplier 69	179	0,05263
184	Supplier 78	180	0,05263
185	Supplier 89	181	0,05263
186	Supplier 99	182	0,05263
187	Supplier 201	183	0,05263
188	Supplier 31	184	0,05263
189	Supplier 43	185	0,05263
190	Supplier 45	186	0,05263
191	Supplier 51	187	0,05263
192	Supplier 84	189	0,05263
193	Supplier 104	191	0,05263
194	Supplier 117	192	0,05263
195	Supplier 127	193	0,05263
196	Supplier 142	196	0,05263
197	Supplier 157	198	0,05263
198	Supplier 182	199	0,05263
199	Supplier 188	200	0,05263
200	Supplier 199	201	0,05263
201	Supplier 169	44	0,02632

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